The 10th OUGS Conference

It was fitting that our anniversary Conference should be kicked-off by one of the Society's staunchest supporters at the OU, Geoff Brown. Geoff treated us to a geothermalogue (a geothermal travelogue!) of current European activity on the geothermal front. He started with Italy, the only country other than Iceland where, today, any significant percentage of the electrical production is from geothermal sources.

At a well near Pisa in Tuscany, steam arriving at the surface from a newly bored hole has a temperature of 200°C and a pressure of 4 or 5 atmospheres. This area has been known for its geothermal energy for some time. Fifty years ago there was quite a flourishing chemical industry at Larderello that was based on the borates and other minerals deposited by geothermal waters coming to the surface. As the deposits were assessed by the local surveyors using the primitive auguring tools common in that period they would quite often break into a reservoir of hot steam. At the time it was considered a nuisance, but nowadays a more constructive attitude is taken to such discoveries.

If you study a cross section of the region you find that the steam is stored in an aquifer of brecciated limestone that sits between an impermeable caprock and the local basement gneiss. The limestone was brecciated by thrusting movements producing a rock containing fragments of limestone, dolomite and gypsum. Water that percolated through this formation dissolved much of the gypsum, so increasing the permeability. Nowadays steam is produced by drilling 2km into this aquifer, which is situated over a magmatic heat source that represents part of the igneous activity on a complex destructive margin, and is slowly becoming less active.

Over the last fifty years the natural surface emanations have dwindled as more and more of the water and steam in the aquifer have been pumped up. There are several power stations in the area, which is crisscrossed by aluminium pipes carrying the steam. These pipes are treated by the local inhabitants as a tourist attraction rather than an eyesore, though they are a bit of a nuisance if they leak sulphurous gas outside your hotel bedroom all night!

Power stations using geothermal energy look much like conventional power stations - if you ignore the pipes feeding them. The steam can be passed straight into a turbine and then exhausted directly into the atmosphere, but a greater efficiency can be obtained by condensing the steam back to water on the low pressure side of the generator to create a greater pressure drop across the turbine. In the Laderello region some 400 megawatts of geothermal capacity are currently being exploited, representing about 1.5% of Italian electrical demand.

Some attempts are also being made to develop fields near Rome but, because of the alkaline nature of the volcanic ashes in this area, the steam produced is highly saline, which causes severe corrosion problems for the few pilot plants that have been started up in the region.

Further south the volcanic activity in the Bay of Naples has led to some development on the north of the bay, in an area known as the Phlegrean fields. These are volcanically active, but not as spectacularly so as on Vesuvius. In the Terme area of Naples there are wastelands with natural geothermal emissions. One of the local hotels does a roaring trade with American tourists in face compresses, etc, from the local mudpools. Here the rocks have a high proportion of sulphur and tend to decompose into soft, crumbly rocks. Sulphur dioxide is an important gas in these fields, and as a result the corrosive water pumped out cannot be used in the public supply. This means it has to be recirculated. By doing this as quickly as possible after the steam has been condensed in the power station it is possible to reinject the water whilst it is still warm, so conserving the heat within the geothermal acquifer. The well heads in

this area receive the steam at several atmospheres of pressure, and it is sometimes difficult to obtain high pressure well heads to replace corroded units. As the well heads are close to some of the local habitations this means that whenever one of the valves becomes suspect the well has to be sealed off until a new head can be fitted.

At first sight an active volcano, such as Vesuvius, might seem to offer an obvious source of geothermal energy. At the top the rocks feel hot, and steam still emanates from the crater even though the last eruption was in 1944. Most of the material in the area is very ashy, but there are occasional bands of alkaline lavas rich in phenocrysts of different feldspathoidal minerals. Unfortunately a recently drilled site showed that there was no hot water to be found within 3 kilometres of the surface. This is probably because there is no caprock to seal the water into the aquifer, so any steam produced can leak away - albeit at a fairly slow rate. So, despite its obvious geothermal potential, Vesuvius is not going to provide us with much energy. As with oil wells, the presence of suitable strata and heat sources means nothing if there isn't a caprock to allow the resource to accumulate.

Throughout Europe former volcanic areas are being studied for geothermal potential but, despite work in the Massif Central in France and at Urach in Germany, no other sites in mainland Europe are producing electricity from high temperature, high pressure steam.

But you don't necessarily need high pressure steam to produce geothermal energy. An interesting technique for exploiting zones where, at shallow depths, there are rocks with low thermal conductivity, such as shales, marls or mudstones, that allow a reservoir of heat to build up underneath them, has been developed in France. In the Paris Basin there is a series of aquifers, such as the coarse Triassic sandstone above the basement rocks, which are capped by impermeable, low conductivity strata. This means that, instead of the normal 20°C rise in temperature for each kilometre you get below the surface in typical crustal material, the Paris Basin has a 50°C/km gradient. Whilst this will not allow steam turbine power stations to be used it does allow electric power to be saved by providing hot water that can be used to heat homes and greenhouses.

Whilst we think of geothermal energy as a clean source of power with no side effects, it is perhaps instructive to note that a French geothermal site in the middle of Paris sported the slogan "Oui à la géothermie, non aux nuicances" after three weeks of round-the-clock drilling. If only we could get the energy without the drilling rigs! As yet the French haven't been able to get the pumps for their massive 100 greenhouse complex near Orleans going, but when they do they should be able to reduce their oil bill by the tune of some 4000 tonnes a year. And geothermal energy is a renewable resource, whilst oil certainly isn't on anything like the same timescale.

Coming closer to home, the geothermal techniques developed in the Paris Basin are now being assessed for use in the Southampton area, where there are similar buried aquifers with low conductivity impermeable caprocks. One of the trial boreholes is already destined to provide hot water for space heating in the near future.

Perhaps the most exciting and potentially rewarding recent pieces of geothermal research in Europe, however, is taking place today in Cornwall right on top of the granite batholith. Of course, granite is not regarded as a particularly permeable rock: moreover its thermal conductivity is quite high. Given that Cornwall is not a magmatically active area we must drill to great depth to find useful temperatures and to create an artificial aquifer by opening up fractures in the rock at that depth. The interest in granite is because of its high heat production due to the presence of radioactive isotopes of potassium, uranium and thorium, which occur in feldspars, micas and accessory minerals. That is why temperatures at depth within the granites are higher than in the surrounding rocks.

Researchers from the Cambourne School of Mines, working in a granite quarry just inland from Falmouth, have been carrying out rock mechanic tests by drilling several shallow (300m) holes and making hydraulic connections between them. To do this they exploit the natural fractures

by progressively increasing the pressure of water which they pump into the granite down one borehole until a satisfactory flow of water is found to return up the other holes. Fresh from their successful experiments with the 300m holes, recently they have drilled to 2km to study the mechanical properties of granite at that depth. The final goal, however, is at 5km depth, where temperatures of almost 200°C are predicted from heat flow studies in the Cornish granites. This is the so-called 'hot dry rock' geothermal method and, once developed, it could be used almost anywhere that there are crystalline rocks at depth with reasonable heat production values. Calculations based on the cost of installing and running such a scheme suggest that, over a 30 year lifetime for paired wells, electricity could be produced at just a few pence per kilowatt hour (today's prices).

As a footnote, at the Open University we are contributing to a project (together with the IGS and Imperial College) designed to assess the geothermal potential of Caledonian granites in N. England and Scotland. The Open University contribution has involved measuring heat production for mainly exposed granites. The results have led to shallow heat flow holes being drilled in the most promising locations in the Lake District and Eastern Highland regions. If the remaining experiments in Cornwall prove successful in the longer term then future development of these Caledonian sites might be envisaged within the next decade.

The proceedings on Saturday morning were opened by our President, Dennis Jackson, who undertook to tell us about the developments in the petroleum field in the last decade. A cartoon in Punch showing a gentleman opening his garage doors to show his magnificent Rolls Royce whilst saying "I never use it - I just let the petrol appreciate" epitomises the main impact that petrol has had on us over the last 10 years. It is incredible to think that back in 1970 a barrel of oil cost $1.80, whilst today the posted price is $34, so when you really come to think of the price of petrol in relationship to the price of oil it isn't such a bad deal.

There are three principal factors that can be identified as leading to this price rise. First came the revolution in Libya, then the 1973/4 Arab oil embargo and finally the Iranian revolution and the Gulf War. Each of these led to a distinct hike in the price of oil. It was the underdeveloped countries that really suffered: countries such as Bangladesh, India and Kenya finding themselves with serious economic problems. The situation was no better behind the Iron Curtain, where Yugoslavia, Poland and Czechoslovakia all suffered.

In fact in the middle of the oil crises it seemed that the best place to find oil was in the New York Stock Exchange. Many of the major oil groupings were formed then, or changed hands. Shell bought Belridge, DuPont bought Conoco, US Steel bought Marathon, and so on. At that time such mergers were the cheapest way of acquiring crude oil.

One other noticeable effect of the rise is that the North Sea has suddenly become an economic place to drill for oil. It remains one of the most hostile places in the world in which to drill for oil because of both the depths and the weather. By 1972 quite a few gas fields were in operation but the only oil fields at that time were the Montrose, Forties and Ekofisk fields, and Dennis was talking to S100 students at Reading on the subject of 'North Sea Oil - Bubble or Bonanza'!

In the North Sea gas production has risen from 2500MCF (million cubic feet) a day in 1982 to over 5000MCF in 1982, whilst oil production has rocketed from no production at all to around 2 million barrels per day at the present time. Britain, in fact, reached oil self-sufficiency back in August 1981, only nine years after the first discovery of oil off our shores. Today Britain is second only to Saudi Arabia in terms of off-shore oil production, and is fourth in terms of overall oil production. This is an incredible achievement, which we take all too much for granted.

The 26 off-shore oil fields presently in operation contain, on average, around 400 million barrels each. The largest, Statfjord, is the largest in the world, with 5 billion barrels of oil. BP's Forties field contains around 1.8 billion barrels, over half

of which have already been recovered in the few short years it has been in production - a rather sobering thought! The next generation of fields will be much smaller, averaging something in the order of 100 million barrels each, whilst third generation structures will probably only yield 60 million barrels or so. Before such wells become economical the price of oil will have to rise still further.

Whilst in 1972 the North Sea was thought to have someting in the order of 0.7% of the world's recoverable reserves, it is now estimated that it contains about 5%, with some 13 billion barrels falling within the British sector. In terms of revenue, a total investment of some £25 billion is now, finally, generating a turnover of around £12 billion a year.

Nowadays there is little the oil industry won't attempt to exploit, providing the price is right. The depth of the oil is no longer a problem. Wells up to 12 000m have been drilled in Russia (probably for geothermal energy rather than oil), though in this case the last 1200m took 544 days to drill! All three types of rig, the jack-up, floating and semisubmersible, are in use in the North Sea. With the advent of large concrete rigs, such as the Norwegian Condeep rigs, the problems caused by corrosion of the legs are being overcome. Such rigs can operate up to 36 wells at a time, each drilled at a different angle.

Modern seismic exploration for oil uses large vibrosonds. These look like JCBs with large footpads that can vibrate at different frequencies. Three synchronised machines are used, from which a series of geophones are run to collect the various signals as they are reflected from the boundaries of the different strata. At sea the old, environmentally dangerous, depth charge explosions are being replaced by arrays of large airguns that blast shockwaves into the seafloor. Nowadays up to 120 geophones will be towed behind a ship to record the signals from a single point on the seabed. Another technique now becoming available is bright-spot surveying, which provides a computer-enhanced coloured image of the strata.

Seismic data can be used to provide information on bedding patterns, deposition processes, velocity, density, bedding continuity, fluid content, bed thickness, porosity, etc. This allows geologists to build up a detailed story of sedimentary history. By studying the various transgressions and unconformities, and by constructing computer models to depict the various structures, likely sites for oil drilling can be identified.

The North Sea Basin has provided a number of geological surprises. Before oil exploration started there everybody presumed that any fields found would be of the same size as the minute on-shore fields. The existence of the central Viking graben was a big surprise, as was the Groningen gas field, which was sourced by gas from the Coal Measures, and nobody had contemplated finding oil in chalk, as has been discovered in the Ekofisk and Montrose fields. In the Argyle field we have oil in Devonian strata which were orginally supposed to be a continuous continental series from North America through Greenland to Europe. Now we have evidence for a marine environment smack in the middle. The Jurassic vulcanicity along the central graben is also evidence of the unusual levels of activity in the North Sea region over long periods of time.

One of the reasons why there is so much interest in the Falkland Islands these days is the likelihood that oil will be found there. Oil and gas wells have been drilled on the Argentinian side of the Malvinas Basin, and the continental shelf around the Falklands themselves seems to have the right sort of structure and burial history. Given the current state of off-shore oil production techniques any oil there is certainly recoverable, technologically.

Another area that has changed within the last ten years is the oil geologist's view of geochemical data. Ten years ago the prerequisites for drilling a prospect were porous strata and a suitable cap rock that was not breached in any way. Nowadays the geologist will also have to identify a suitable source rock, and whether it has reached a sufficient degree of maturity. The source rock must contain at least 0.5% of algae, photoplankton, etc, which can be converted to kerogen by organic metabolic activity. Most of the source

rocks are shales, deposited in quiet, anoxic, environments so that the organic material is preserved.

Geochemical analyses tell us whether or not such shales have sufficient organic matter to be capable of generating petroleum, and qualitative studies can predict the kinds of hydrocarbons (oil, wet gas or dry gas). It is important to know this prior to drilling because the economic potential of an offshore oil field is much greater than for a gas field of comparable size.

Another thing which the geochemistry can tell the petroleum geologist is whether or not the source rock has been 'cooked' to the point that it has generated hydrocarbons. Because such a thermochemical reaction is time and temperature dependent, and is irreversible, it is now possible to enter a few parameters, such as palaeogeothermal gradient and thickness of strata, into a computer and to derive answers to questions like 'When, What type and How much hydrocarbon was generated in a basin?'. This data can then be related to the time of origin of structural traps, and the migration routes can be guessed at in the knowledge that faults and porous strata are conduits and shales and evaporites are barriers to migration. Being able to predict the whereabouts of the best petroleum prospects in a basin has contributed significantly towards improving the petroleum industry's success ratio over the last decade.

Professor Dick Owen took as his title 'The Geological Evolution of Britain - Let's take a further look'. In the last 10 years stratigraphy has changed its pattern completely. It used to be a term associated with a series of facts displayed on a blackboard, but the spread of the plate tectonic theory added a new dimension by providing reasons for stratigraphic changes. The OU unit on Historical Geology, in S23-, was a pioneer in the concept of trying to link all the recorded stratigraphy over a complex area such as Britain. We now see such glib phrases as 'the sea came in and it went again', and concepts such as vulcanicity and sedimentation, as part of a much larger whole.

Some of the results provided by radiometric and isotope work in the last ten years have been a little surprising, and have caused us to look closely at our previous interpretations of the stratigraphic column. For instance, some place the base of the Cambrian at 530Ma, whilst the base of the Tremadoc, the official start of the Ordovician, has been dated at 520Ma, giving an age of only 10Ma for the Cambrian succession, but 90Ma for the Ordovician! Poor old Sedgwick must be turning in his grave. Yet we may see written round the edge of every university geology campus the slogan 'Lapworth Rules OK'!

Our knowledge of the Precambrian has been much extended by recent work on isotopes and geochemistry, as well as by a fresh look at its structures. As far as Britain is concerned Scotland is the main source of information on this extremely long period. The natural division of the Precambrian, between the Archaean and the Proterozoic, occurred somewhere between 2000Ma and 2500Ma ago. In Scotland this is represented by the Lewisian, which was much studied by pioneers in the last century, and more recently by Imperial College. The furthest back we have been able to go in the Scottish succession is around 3000Ma, which represents the time that a little British nucleus began to evolve from the mantle. The first important period of deformation, the Scourian, took place around 2700Ma, followed by the Inverian around 2300Ma, a post-Scourian dyke phase, and then the great Laxfordian orogeny about 1850Ma. This whole period is also represented by igneous intrusions, pegmatites and granites, and was followed by a sedimentary phase known as the Torridonian.

Recent research has shown that the picture is a lot more complex than was thought 10 years ago. In particular the Inverian episode and the dyke phase in the middle of the Lewisian seem to have been a lot longer than originally postulated. It seems likely that the Laxfordian orogeny was more important than its name suggests, because current thinking relates it to an early continent-continent collision. Correlations of the Lewisian with rocks of similar age in Scandinavia and Greenland hint that one vast northern crustal plate was formed over this area in the Precambrian.

The Moine supergroup was also thought to be relatively straightforward ten years ago. There was a hint that it might have been the metamorphic eastern equivalent of the western, unmetamorphosed, Torridonian, but we now recognise divisions within the Moine, and the episode is recognised as covering quite a large timescale. In the southwest Highlands of Scotland the Mora Moine could well be 1000Ma in age, whilst some of the younger Moine deposits may have bypassed the Torrodonian group. The radiometric data yields ages of 1050Ma, 750Ma and 400Ma (which probably represents the imprint of the Caledonian orogeny). During the next ten years a lot more work will need to be done to sort out the palaeogeographies associated with the Moine and Torrodonian deposits. Several Moine areas in the northwest Highlands may now be far away from their sites of origin.

The Dalradian is another area that has received a lot of study over the last ten years. Here the accent has been on sedimentological and structural aspects. Terms such as M1, M2, M3, M4, F1, F2, F3, D1, D2 and D3 are used to describe various structural phases (much to the confusion of those brought up on Carboniferous geology, where D2 has a completely different meaning!). The top part of the Dalradian is now thought to be in the Lower Palaeozoic, rather than the Precambrian. The 47 Dalradian tillites (fossil boulder clays) have been dated at around 668Ma, right at the end of the Proterozoic, which corresponds with the times associated with similar deposits as far apart as Scandinavia and Morocco. As Norway was on the equator, Britain at 15°S and Morocco at the South Pole during this period the idea of a glacial origin is a bit hard to swallow. The tillites are interbedded with dolomitic limestones, indicating a warm water environment. Perhaps the next ten years will reveal the answer to this riddle.

One interesting theory to emerge from the Scottish studies of the last decade occurred recently in a paper in the *Journal of the Geological Society*, where it was suggested that the Moine Thrust, and other important thrusts in Scotland, may have originated at the M discontinuity. They may be related to something much deeper in the foundation of Scotland, and could represent very fundamental breaks in deep crustal regions dating back to Precambrian times.

Precambrian rocks can also be found in the St Davids area of Pembrokeshire (Dyfed), but in the last 10 years an extra-mural adult education class run by John Cope of the University of Swansea have also found Precambrian deposits about 2 miles southwest of Carmarthen. Precambrian rhyolites accompanied by bands containing jellyfish dated at 700Ma, Upper Cambrian sediments containing trilobites, Tremadoc deposits containing trilobites and dendroid graptolites and Ordovician volcanics were all in an area previously classed as Red Marls! The new Precambrian deposits are now being tied up with the English deposits at Charnwood and Malvern, and with the Benten volcanics of South Pembrokeshire. The cause is still unidentified, but again the next ten years could provide us with a key between these deposits and ones of similar age in Brittany, the English Channel and Cornwall.

There have been three catastrophes in Welsh history. The first, and by far the biggest, was when Scotland beat Wales at Cardiff Arms Park!! The second big surprise and upset has been the finding of the thick Lias succession in Cardigan Bay, off Mochras, where there ought to have been a land area according to the palaeographic atlases. How dare they have 1500m of Lias in Cardigan Bay!!

We don't know how real the third upset is as yet, but people like Max and Barber have caused us to look again at Anglesey with their suggestion that the ophiolites, serpentinites and high pressure, low temperature metamorphic rocks may be Lower Cambrian rather than Precambrian. The Lleyn Peninsular, which is really just a part of Anglesey tacked onto North Wales, contains limestones (in melanges) that are Proterozoic in origin, so there must have been Precambrian sedimentation of a shelf variety, but the matrix of the melange that this limestone is found in contains Cambrian microfaunas, as do the jasper infillings in the pillow lavas of the same group. This has caused many of us to redraw the diagrams of what was happening underneath Anglesey 700Ma to 500Ma ago. Again this is an area that won't be fully resolved for another ten years.

Plate tectonics has given a new breath of life to the unravelling of the geological picture in every region. The only unfortunate thing, perhaps, is that Britain moved away from the active areas of the plate tectonic scene from the time of the Old Red Sandstone. Before that there was an ocean between Scotland and Wales. Unfortunately it wasn't there last February!! The size of the ocean between the two countries has been estimated at between 500 and 4000km. In view of the £61 train fare from Swansea to Aberdeen the latter estimate seems to be the one used by British Rail! Graham Hall's article in the last issue of the Journal summarises the current story rather well. It was John Dewey who first tried to unravel the way the plates subducted. Since then many different theories have been put forward (see the excellent book by Anderton et al.).

At Glasgow University a lot of recent work has been done on the isotope and geochemical composition of the Ballantrae complex on the Scottish side of this ocean. The metapyroxinites in this complex may represent quite deep welded bits of the crust that have come up in an obduction zone. This area is now thought to represent a back island arc with a marginal basin similar to the type of thing we see around Japan today. It seems there was a period of stretching which allowed some of the crustal material to upwell some 35km in a relatively short space of time.

Further north the Highland Boundary Fault and the Highland Border Series may also indicate another phase of opening within this Iapetus Ocean, before the Ballantrae opening. Again the area is rich in the serpentinites and cherts we associate with such events.

Brian Bluck's work on the Silurian sedimentation on the southern edge of the Midland Valley of Scotland has identified three types of conglomerate. The lower two (Wenlockian) phases are derived from volcanic material formed in a volcanic arc, which may have been deposited as far from the current deposits as about where Cardiff is now. The third phase was an accretionary one, which may have taken place in a trench that is now under the Southern Uplands.

Looking to the south of Anglesey, there may be a late Proterozoic (Cadomian) subductive episode, linked, perhaps, with an African movement, that accounts for the heat rise that caused the Charnwood and South Pembrokeshire volcanic episodes. We are still uncertain about whether there was a Variscan subduction zone in the area of the Lizard in Cornwall. A late Devonian back-arc sea is indicated here.

Plate tectonics has also allowed us to understand why there was an early Jurassic transgression in the Mesozoic, followed by a later regression, and yet another, Cretaceous, transgression. This can now be linked to the opening up of the Atlantic Ocean, as we now know it, and the effect of the new 'mid-ocean' spreading ridge rising up initially, then sinking somewhat.

It is possible that the Permo-Mesozoic rifts in the North Sea, that are now of such interest to people such as Dennis Jackson, are evidence for earlier attempts at forming an ocean. If it had succeeded we would, perhaps, have been driving around in huge American cars! The Middle Jurassic volcanics of the Forties and Piper fields are some 1500m thick, which is thicker than the Snowdonian volcanics. In the Fastnet area there are a series of Jurassic dykes, so the line of heat may have migrated during the period from the North Sea to the area around the Porcupine Bite and Rockall.

Our vastly increased knowledge of the sea floor that surrounds us has also been obvious in the last decade. This new area is twice as big as the landmass that we have been concentrating on up to now, and it is providing a lot of unexpected results. We have now found that the Westphalian Coal Measures of the East Pennine coalfield spread all the way across to The Netherlands and northwest Germany. Again, a major unconformity occurs within the Cretaceous of this seafloor geology and plays an important part in siting oil reservoirs. The Tertiary deposits in the North Sea reach considerable thickness (over 3000m in places). We now eagerly await further great surprises from this area in the next ten years!

Our final speaker of the morning was Professor Tony Hallam of the University of Birmingham, who took as his subject 'Evolution and Biogeography'. The last decade started with a paper on evolution by two Americans, Eldredge and Gould, which caused quite a stir, and with the publication of the *Atlas of Palaeobiogeography*. The story shown in the Atlas had been unfolding since the beginning of the century, when it became obvious to palaeontologists that the Mesozoic fauna of the southern continents was common to all three continents, despite the manifest differences between their present-day faunas. A number of theories were put forward to explain this, the most popular of which involved a landmass which linked Africa and America, and another between Madagascar and India, which later sank beneath the waves. Within a decade or two the problems with such a theory were being pointed out by the German scientist Alfred Wegener. Gravity measurements indicated that the ocean crust was fairly dense, and all the outcropping oceanic islands were composed of basalts. The only reasonable solution seemed to be that the continents were joined together during the Mesozoic. However, it took some time for this idea to be accepted by the geological community.

It is now accepted that, as two continents converge, faunas mix to ever greater degrees. The more mobile marine species are the first to migrate, whilst the sessile and terrestrial species only start to mix as the continents begin to collide. Applying this concept to the closing of the Iapetus Ocean that Dick Owen was just telling us about, we find that the Cambrian faunas of North America, Newfoundland, Nova Scotia and Scandinavia are very similar, but markedly different from those of the rest of Europe. At an early stage the graptolitic and planktonic faunas became common, followed by the trilobites and the brachiopods. It was not until the Devonian that the freshwater fishes became common to both provinces. And between the two provinces we have the Caledonian fold belt.

Whether there was just one supercontinent in the Mesozoic, or whether there were two, Gondwana and Laurasia, is still not certain. Whilst the two parts were possibly separated during part of the period it is likely that they were joined together at certain points for much of the time. The cosmopolitan nature of the reptile and dinosaur range can be used as a pointer to how well connected they must have been.

In the Cretaceous and Tertiary the picture changed yet again, with the break-up of the supercontinent and the formation of the continents we know today, each of which developed its own characteristic fauna at quite an early stage.

Whilst the terrestrial animals are more likely to diversify as continents diverge, the truly marine species are more likely to diverge as continents converge. This is because they become cut off from each other as the seas they inhabit become landlocked, or because they now have huge distances to travel to get from the location of one species to that of another.

The latest evidence for such behaviour comes from the formation of the Central American land bridge. This led to cross-migration between the Late Tertiary faunas of North and South America, but resulted in a divergence of the marine populations on either side of the landmass.

The Tethyan seaway is based on evidence of a similar change in the faunas of Africa and Eurasia around the Lower Miocene. Until then the two land-based faunas were different, but by the Miocene the African and Asian terrestrial faunas intermixed throughout the region. About the same time there is a marked divergence between the marine faunas found in the Mediterranean and Western Atlantic from those found in the Indian Ocean. Previously one fauna had occupied both oceans.

An area currently of interest to both palaeobiologists and geologists is the area bordering the North Pacific. For some time it has been realised that California, Oregon, South Alaska, parts of Eastern Siberia, North China and Japan do not belong to the same geological provinces as their neighbours. Magnetic surveys suggest that all these rocks were at a different palaeo-latitude in the Mesozoic. In all of these areas the rocks contain faunas which are not found in the adjacent

regions and which were more associated with tropical areas. It seems likely that there was a totally independent China block on the equator in Permian times, which later broke up and scattered around the edge of the Pacific. Perhaps the next ten years will clarify the situation in this region.

As far as evolution is concerned the main subject of debate over the last decade has been speciation. It all started with a paper presented by Eldredge and Gould in a symposium volume called *Models of Palaeobiology* published in 1972. This paper challenged the then conventional model that species evolved gradually, an idea that had developed from Darwin's teaching. Whilst any ornithologist will tell you that species at present are restricted to particular regions, most palaeobiologists had presumed their introduction and withdrawal was a gradual process.

Eldredge and Gould challenged this. Eldredge had been working on the Devonian trilobites in the eastern USA. The evidence here shows that species persisted for millions of years with unchanged morphology before there was a comparatively sudden change. Gould's work on Pleistocene land snails showed a similar pattern at the other end of the geological scale. They suggested an alternative mode of speciation, called punctuated equilibria.

In the past sharp changes have often been dismissed as representing gaps in the fossil record. It now seems that we need to re-examine the old evidence. Eldredge and Gould's proposed pattern of change suggested that speciation events were relatively common, but that most of them were short-lived. On top of this there was a level of what they called macroevolution, which resulted in the major morphological type changes. The two types of speciation appeared to be decoupled.

When you come to look at the fossil record itself the new concept presents some snags. Fossils are rarely discovered in uniform abundance throughout a formation. You tend to find them crowded together in thin horizons. This is especially true of the invertebrates. When the various abundances are plotted on graphs there tend to be large gaps between the sample spots. These gaps can be thought of as representing either the gaps in the fossil record or the periods of morphological stability.

A rival theory is that put forward by the Cladists (from the Greek *clados*, branch). They claim to recognise the affinities of newly emergent species from what they term 'synapomorphic characters'. This is said to preclude recognition of ancestors, but to aid the recognition of 'sister' species derived from the same ancestor.

When more than one theory has been put forward scientists normally try to devise experiments to distinguish between them. For the palaeontologist this is very difficult to do. He must ensure that his sample area contains no gaps in the sedimentary record, and must choose a species for which there is a steady record. For instance, it is no good relying on terrestrial mammals because their remains are normally destroyed after death. We need to use a group with a high preservation potential. In the Jurassic the ammonites provide one such group which has been extensively studied. They have also been used to provide dating and correlation material for those studying the Jurassic oysters known as *Gryphaea*. This is a very abundant genus that appears all around the world. By studying the European variants it is possible to remove the effects of migrationary habits on the studied sample.

One of the easiest species to study is the so-called Devil's Toenail, *Gryphaea arcuta*, whose strongly incurved left valve and rather high ratio of length to breadth makes it easy to identify. In the Early Jurassic this variety of *Gryphaea* was fairly common, but after a few million years there was a distinct uncurling and change in the ratio of length to breadth. At the same time the shells became thinner. By the time you get to *Gryphaea gigantica*, in the Middle Lias, it is hard to recognise that the species are related. These changes can be plotted across Europe, and are used for correlation with fossils as far away as Hungary and the Iberian Peninsula.

The data obtained from the study of thousands of *Gryphaea* over a large area indicates that there is a genuine element of evolution between the species which cannot be correlated with changes in the environment due to the changing sea levels. There seems to be a distinct increase in size that suggests that the concept of the survival of the fittest was at work. If you take a detailed look at the growth rings under a microscope you find that structures that occurred in juvenile *Gryphaea arcuta* are also found in the adult *Gryphaea gigantica*.

The evidence from *Gryphaea* seems at first to point towards the gradualisitic concept of evolution that has been around for some time, so what evidence is there for punctuated equilibrium? There seems to be no evidence in the *Gryphaea* data of there being more than one species at a given horizon, so there is little evidence of lots of species being generated at numerous intervals. Given the numbers of *Gryphaea* that have been collected in Europe over the last 200 years one would have expected that any evidence for such a hypothesis would have come to light by now. But it is true to say that the species do tend to stay the same for periods of millions of years, and that this is followed by a relatively sudden switch to a newer species, so it seems that the concept of punctuated equilibrium raised by Eldredge and Gould can be used to explain the *Gryphaea* data.

Perhaps in the next ten years we will see further evidence to support this hypothesis coming from the micropalaeontologists. To date their work has mostly been concerned with stratigraphic correlation and with the study of oceanography. But planktonic foraminifera could well prove to be an ideal source of data for those interested in proving the punctuated equilibrium concept.

A paper published in America last year by Jack Sepkoski identified three main marine groups of fossils. The original fauna was the one that flourished in the Cambrian, the main elements of which were the trilobites. This fauna declined in the Ordovician and all but disappeared by the Permian, but relict species still survive. The second major group was dominated by the brachiopods, and they flourished through most of the Palaeozoic before, again, being virtually extinguished in the Permian. The third, modern, fauna is dominated by the molluscs, which turned up in the early Palaeozoic and gradually grew in importance.

It has been estimated that in the Permian some 96% of marine species died out. This sort of figure makes the more widely known Cretaceous extinction seem like a mere hiccup, but it and similar events at the end of the Ordovician and of the Triassic are still of great significance. Darwin presumed that species evolution was controlled by biological factors, but we now know that most of these periods of speciation correspond to periods when the Earth's crust was breaking up or rejoining. Those few that cannot be so correlated are often 'blamed' on an increase in radiation levels rather than being given a biological explanation.

If you look at the Mesozoic ammonite record you can see cycles where whole series flourished and then became extinct. There was a mass extinction at the end of the Palaeozoic, and another at the end of the Triassic that only one or two families survived. It is a sobering thought that a slightly more intense event at the end of the Triassic might have left us with no ammonites to correlate the Jurassic and Cretaceous with. In fact most of the extinction phases can be correlated with regressions of epicentral seas caused by the changing plate tectonic situation.

Modern ecological studies fit in rather nicely with these findings. They show that the size of the area involved has a large effect on the number of species. Wherever the area is reduced the number of species also falls.

As the major visible effect of plate tectonic activity seems to have been the changes in sea level it seems likely that this is also the major control on marine, and possibly terrestrial, speciation. It seems unlikely that there were any major changes in the depth of the seafloor, and there is little evidence to indicate the formation of very large icecaps in the relevant periods. So we are left with the thought that there must have been an overall change in the capacities of the oceanic basins. As a spreading ridge forms there is a rise in the level of the seafloor in the vicinity of the ridge. It is not until some time later that the floor sinks down to

its final level. As there was a high spreading rate in the Late Cretaceous we should expect a larger area of ridge material to have been formed, which would explain a rise in the general sea level at this period.

Actually these concepts are not really confined to the last decade. At the beginning of the century an American called T C Chamberlain argued that major evolutionary events were related to tectonism, and hence to the magma underneath us. Perhaps the next decade will see another old theory vindicated.

The afternoon session started with the OU's own Professor Ian Gass talking on 'Plate Tectonics over the last 1200Ma'. Ian started by noting that for almost two centuries geologists have been using the concept of uniformitarianism in interpreting the geological record. In some cases one feels that, maybe, they are pushing their luck just a little bit, and in other cases the concept of reverse uniformitarianism seems to apply better.

Several examples of straight uniformitarianism come to mind. For instance, Crater Lake (actually a caldera lake) in America is recognised as the remains of a massive volcanic mountain, known to American geologists as Mount Masama, which blew its top about 8000 years ago. In many respects it is similar to Mount St Helens, which erupted a year or so ago. Whilst the top of Mount St Helens has not collapsed yet it will probably do so in the near geological future. That's a bit of reversed uniformitarianism!

The eruption of Surtsey in 1962 also provided evidence for the formation of new volcanic islands. We saw how the formation of a tuff ring was necessary before the lava could flow freely, without having to react with seawater. The term decrepitation is used to describe lava that has reacted with water! Fort Rock, on the Oregon Trail, is an example of a similar structure within the Cascade chain of mountains. In this case the island probably formed in a lake rather than the sea. Bevels in the edge of the tuff ring show the level of the lake at the time of the eruption.

Cross bedding in sandstones is often used as evidence for sand dunes, with their implied desert conditions. But similar bedding can be seen in sand bars, and in dunes on the sea shore, so details such as ripple marks, load casts and other sedimentary structures are needed to unambiguously determine the origin of a deposit. Similarly, although stromatolites have been used by some Russian geologists as time fossils to identify the various zones within the Proterozoic, the presumption is usually made that they all formed in the warm shallow waters that are the typical home of modern stromatolites.

One thing that all the above processes have in common is that they are surface processes. When it comes to internal processes it is a lot harder to apply the principle of uniformitarianism, mostly because we have no clear idea of what is happening now. Plate tectonics can, however, now be used to understand some of the past internal workings of our planet. It can also be used to extend our understanding of the geological record back at least 1200Ma into the past.

The basic premise is the same. What is happening today must be similar to what has happened in the geological past. Our knowledge of what happens at present-day spreading ridges, with their pillow lavas, dykes and underlying layered gabbros, is based on the geological record that was produced at fossil constructive margins. For instance, in rock outcrops we find at the surface today we can see and interpret what happened inside magma chambers - a locale where no direct evidence will ever be available.

The main features of the surface of the Earth can be divided roughly into the stable plates, the constructive areas along the spreading ridges and the destructive regions along subduction zones. Other features do disturb this pattern. For instance, volcanoes can be punched through a plate over hotspots, as is shown by the Hawaian chain of islands.

Again, reversing uniformitarianism, we interpret gossans, such as those found in Oman, as the result of hydrothermal action of seawater percolating through a spreading ridge, and postulate that

similar deposits of iron, copper and zinc could be forming at modern spreading ridges. In the last decade oceanographers, following the lead of geologists, who have been exploring the East Pacific Rise have identified 'black smokers' that are precipitating copper and zinc bearing sulphides from hot brine emissions. This data can be used, as an example of normal uniformitarianism, to show how some of the sulphide ore bodies we see in the geological record could have been formed. But the original motivation for the search was the past geological record.

The andesitic composition of the Cascade range of Northwest America, the Andean chain and the Japanese arc, is used as evidence for an underlying subduction zone. Similarly the island of Tristan da Cuhna can be equated with Hawaii as both are examples of within-plate basaltic volcanoes. The geochemistry of their basalts suggests the presence beneath them of a thermal hotspot.

Over the last decade we have come to realise the importance of the strong, high field-strength, trace elements such as niobium, yttrium, titanium and zirconium in providing evidence of the source of a rock that has been affected by pressure metamorphism. We now know that within-plate basalts are relatively enriched in zirconium, and that the zirconium/yttrium ratio tends to be depleted in rocks generated in subduction zones. By plotting the ratios of these two elements in ancient greenschists, and comparing them with results obtained from more recent crustal material, it is possible to indicate the type of igneous environment in which the now metamorphosed rocks were formed. This is possible despite the fact that the original structure of the greenschists has been completely lost because the 300-350°C temperatures have broken down the original minerals, such as pyroxene, plagioclase, olivine and quartz. A similar technique is also available for acidic and granitic rocks. In this case the ratio of niobium to silica is used to identify acidic rocks emplaced within ancient continental plates, such as are found in Nigeria. Again granites associated with subduction zones have much lower niobium contents than those emplaced elsewhere.

This method is very useful in places like the Arabic-Nubian shield. Here the calc-alkaline nature of the granites has been interpreted by American geologists as evidence for a Proterozoic subduction zone. They even used the direction in which the rocks become potassium enriched as evidence for the dip of the subduction zone. As the granitic material was between zones of ophiolite complexes, the idea of a series of island arcs separated by oceanic lithosphere has been postulated for the area. You can find examples of Andean-type vulcanology here, with granite bosses within andesitic tuffs and ignimbrites, as well as greywacke-like sedimentary structures normally associated with such environments. You also find limestones with stromatolites. Today such deposits are associated with lagoonal areas typically found in island arcs. Here we find them as sedimentary rocks some 800Ma old.

In the north-east of Sudan there is a belt of granite which is flanked by pyroclastic volcanic sequences and then by sedimentary sequences of greywackes with occasional carbonates. We now envisage for this region an Archaean continent, represented by the Nile Craton, flanked by a series of island arcs which collided to form a new continental area, with granites being intruded as part of the process. The whole shield is now some 35km thick, and it probably formed over a 600Ma long period starting some 1200Ma ago. Perhaps in 600Ma time we will find that the western Pacific area, around Japan, has formed another new piece of continent.

Titanium against zirconium ratios are used to identify ophiolites, but here lies the cautionary part of the tale - most ophiolites we have identified so far formed above subduction zones. Maybe this is because the oceanic crust formed in this tectonic locale, above a subduction zone, is thinner and hence can be obducted more easily. The oldest ophiolite identified to date is less than 1200Ma old. As we find ophiolites this far back, and as the heat flow 1200Ma ago was probably similar to what we have today, the evidence suggests that the Earth then was thermally similar to the present-day situation and that tectonic processes probably had similar dimensions and operated at similar rates to those found today.

Going back further in geological time the picture becomes more confused. Although it seems likely that plate tectonic processes operated throughout the Proterozoic and Phanerozoic, we have no definite ophiolite evidence to support this possibility further back than about 1200Ma. Perhaps the next ten years will provide further evidence.

Our final speaker for the first day was Dr. Beverly Halstead of the University of Reading, who undertook to speak 'In Defence of Darwin'. This year marks the centenary of Darwin's death but not, fortunately, the death of Darwin's ideas. The last decade has been a most controversial one as far as the latter are concerned, because of the concept of punctuated equilibrium put forward by Eldredge and Gould.

The whole concept of evolution is incredibly simple. It involves the theory that changes are the result of a series of small modifications that help the organism better fit its environment. This process is known as natural selection. It encompasses the concept that an equilibrium exists which ensures that all offspring do not survive to reproduce. Basically the genius of Darwin can be boiled down to the ability to substantiate these simple ideas.

The threat to Darwin's ideas probably stemmed in part from an official report to the Trustees of the Natural History Museum in 1972, when it was recommended that the museum should become more concerned with communicating the concepts of science to people without a scientific background. This led to the staff being introduced to the work of Sir Karl Popper that suggested that scientific theories should be so formulated that an experiment could be devised that would prove if the concept was false.

At this stage cladistics entered the geological repertoire. Based on ideas put forward by a German, Wilhelm Hennig, this suggested that taxonomists should be able to uniquely identify each different form of species. This concept worked fairly successfully for live organisms, so it started to be applied to the fossil record, by using it to classify those fossils that still have living representatives. Suddenly we found that it was being applied to all groups of fossils.

In the late 1970s the British Museum started to prepare an exhibition on Evolution. In response to a letter received from a creationist, the head of the Public Services Department promised that "in this exhibition it will be stated that evolution is not a scientific theory in the sense that it cannot be tested or refuted by experiment: that evolution is a metaphysical theory". In the book they published on evolution in 1978 the museum asserted "If we accept Popper's distinction between science and non-science we must ask first whether the theory of evolution by natural selection is scientific or pseudo-scientific, metaphysical. This implies that because evolution is concerned with the history of life as a simple process of species splitting and progression it is a historical theory and, therefore, not part of science because it is not subject to test." Can you imagine what would happen if palaeobiologists and geologists asked the Science Research Council to fund research into metaphysical projects!

When it came to the dinosaurs included in the exhibition the museum told its expert in dinosaurs that what went on in the exhibition was none of his business. Similarly the anthropolgists were consulted regarding the fossil man exhibits, but their views were overruled. What eventually happened was that the exhibition presented the dinosaurs and fossil men as proof of the validity of the cladistic approach.

The cladistic concept as put forward contains two assumptions. Firstly, that new species arise when one species splits into two. Secondly, that none of the species being considered is the ancestor of any of the others (they are all sister species). If the first assumption is accepted, it must also be presumed that when you have three species they were produced by two splits, one after another. Unfortunately this theory is inherently untestable, yet cladistics is claimed to be a scientific activity which conforms to the definition of science put forward by Karl Popper.

One of the conclusions that can be drawn from this, which the creationist leapt on, was that there

are no fossil species directly ancestral to man. So whilst anthropologists at the Natural History Museum were writing articles describing the gradual transition of *Homo erectus* into *Homo sapiens*, an exhibition in the public galleries was saying that *Homo erectus* was quite separate, much to the creationists pleasure. In the exhibit a 'primitive' *Homo erectus* skull was placed next to an 'advanced' *Homo sapiens* skull on a turntable to exhibit the differences. The booklet explains that they are 'not directly related'.

The creationist movement also really got under way in 1972. Its biggest achievement this decade probably occurred when Ronald Reagan came down on their side. The three planks that they used in their case in the Arkansas courts were: what constitutes science, the concept that cladistics show that you cannot identify ancestors, and the concept of punctuated equilibrium. The first plank is based squarely on Popper's concept of science and the concept that evolution is really a metaphysical theory. The second argues that you can only recognise splits by the presence of 'advanced characters', and that the presence of 'primitive characters' cannot be used to identify an ancestor.

What many people do not realise is how much Popper's views were coloured by his Viennese education. As a Marxist he was involved in a student demonstration at which a number of students were shot. He then realised that what the communists were trying to do was to accentuate the problems in society so that they would reach a critical point that would result in a sudden change to a higher state. This was claimed to be based on the scientfic laws of history. Popper has spent his life in proving that by definition there cannot be scientific laws of history. In doing so he has screwed up all historical sciences, including palaeontology.

Marxists today recognise punctuated equilibrium as a perfectly acceptable way of interpreting the fossil record. Whilst the concept has only been around since 1972 Darwin himself was aware of the problems associated with the gaps in the record. He said "the abrupt manner in which whole groups of species suddenly appear in certain formations has been urged by several palaeontologists, none more forcibly than by Professor Sedgwick, as a fatal objection to the belief in the transmutation of species. If numerous species belonging to the same genera or families had really started into life all at once, the fact will be fatal to the theory of descent with slow modification through natural selection. ... Why then is not every geological formation and every stratum full of such intermediate links? Geology assuredly does not reveal any such finely graduated organic change and this, perhaps, is the most obvious and gravest objection which can be urged against my theory. The explanation lies, as I believe, in the extreme imperfection of the fossil record."

Darwin presented the Marxists with a world that, for once, was based on change. He pointed out how you must study species in the context of everything that impinges on them. As Engels said, "Hard and fast lines are incompatible with the theory of evolution". But another Marxist, Stephen Gould, looked on Lyell and Darwin as phyletic gradualists. What he said was that Darwin was simply reflecting a sort of mid-Victorian capitalism, quoting Karl Marx's "it is remarkable how Darwin recognises among beasts and plants his English society, with its division of labour, competition, opening up of new markets, invention and the Malthusian struggle for existence".

The creationist claim there is now no evidence for gradual evolution and that what we see is a series of abrupt changes. They see no process that can be put forward to explain these jumps other than the idea of species selection. This new concept of macro-evolution denies the neo-Darwinian theory of the importance of the individual.

It is only in the last year that the three strands of anti-selectionism, anti-adaptionism and anti-gradualism have come together into a single philosophical pattern of essentialism opposed to the neo-Darwinian synthesis. In the next decade the scientific community will probably continue the struggle for the survival of these ideas.

On Sunday morning Dr Bob Ixer of the University of Aston woke us with a talk entitled 'Ore Petrology and the Origins of Mineral Deposits'. Whilst not one of the glamour areas of geology, a lot has happened in the last ten years, and in the ten years before that. The 70's have seen a dramatic change in emphasis concerning two major classes of mineral deposits: those formed at low temperatures within sediments and those formed by a combination of volcanic and sedimentary processes on the ocean floor.

Low temperature mineral deposits include the lead - zinc - baryte - fluorspar mineralisation in the Pennines, the Colorado uranium deposits, the Zambian Copper Belt and the 'red-bed' deposits. Examples of mineral deposits that are now thought to be due to a combination of volcanic and sedimentary processes on the seafloor include Kuroko and Beshi-type deposits, and many massive pyrite-chalcopyrite deposits.

Why have these changes in emphasis occurred? Principally it is because we now have a greater understanding of the processes of ore formation. The parameters that affect the formation of these mineral deposits include pressure, temperature, fluid chemistry, partial pressure of oxygen and of sulphur and the presence or absence of biological activity. This last consideration is one that was not thought to be of great importance fifteen years ago but which is now of prime interest.

In the 1950s the main technique used to study the origin of mineral deposits was the investigation of polished sections under a reflecting light microscope, using the ore-microscopists's Bible, Ramdohr's *Ore Minerals and their Intergrowths*. In addition to identifying the minerals present, the types and causes of the intergrowths could, sometimes, be inferred. However, it was not until the 1960s that the importance of the total assemblage in which the minerals were found was realised.

It was also at this time that detailed chemical analyses became readily available. Nowadays it is possible to do in one day the same number of analyses as would have taken a whole year in the 1950s. Other new techniques include the analysis of single minerals by the electron microprobe, the study of individual crystals under the electron microscope, and stable isotope and fluid inclusion analysis. Equally important has been the research into the synthesis of minerals within the laboratory. This work has been especially useful in determining the stability fields of sulphides.

The new techniques have not completely replaced the old ones, they have only supplemented them. We have, fortunately, lost the propensity to attribute everything to a volcanic hydrothermal origin and have, therefore, revised the classification schemes used accordingly. We now recognise that the group of sedimentary mineral deposits extends beyond the oolitic ironstones, the titanium rich beach sands, the laterite and the bauxite deposits, into deposits containing lead, zinc, copper, sulphides, etc.

Of course there are still Vulcan-inspired deposits. One close at hand is the one associated with the granites of Jersey, where a silver mine operated for all of 18 months before being closed because of the 'drunkenness of the miners' (an apt warning on the morning after the night before perhaps!)

Fluid inclusion studies have been with us now for twenty years, but in the last decade we have really come to appreciate how useful the direct measurement of these fluids can be. In particular you can ascertain the temperature of entrapment, which is the temperature at which mineralisation occurred. Also the chemical composition of the fluids can be obtained very accurately, giving a good indication of the overall composition of the mineralizing fluids at the time of deposition. It is this field, more than any other, that has alerted us to the importance of low temperature mineralisation. Fluids contain very few sulphides, and tend to be metal rich, and rich in chlorine and potassium. They are also ideal for the study of stable isotope percentages within minerals. Their lack of sulphur, however, makes them more difficult to use for the determination of the $^{34}S:^{32}S$ ratio vital to the proof of a biogenic origin for a mineral.

The 1970s have seen a growth in the interest in the way biological processes affect mineral deposition. It has been known for a long time that

sulphur is metabolised, but not necessarily excreted, by bacteria. Anaerobic, sulphur excreting, bacteria have been studied for their importance in sulphide formation since 1910. It was thought that they could change the amount of sulphur in a fluid, so causing the sulphides to be preferentially precipitated. By the 1960s they were found to be capable of surviving under a wide range of conditions of pressure, temperature, pH, eH, etc, and were thought to be involved in low temperature ore formation. At this stage a number of experiments on bacteria were undertaken to find out the conditions under which they would cause the common sulphides to be deposited. These experiments confirmed that the ^{34}S:^{32}S ratio was a good guide to the presence of a biological agent in the formation of some sulphide deposits.

A number of types of biological activity were found to be very good at concentrating metals. Marine plants were notable for their concentration of heavy metals, some animals incorporate metals into their structures and, as mentioned previously, bacteria are very good at metabolising sulphur. It has even been suggested that the galena in the South Pennines has been derived from the lead in coral skeletons.

As well as the biological deposition of sulphides a lot of work has been done recently on the conditions needed for precipitation of sulphides. Early attempts to generate sulphides under laboratory conditions dealt mainly with the metal sulphides that were formed at relatively high temperatures, but more recently studies have been done at temperatures around 200°C. Hopefully during the 1980s even lower temperatures will be investigated.

Using these techniques on suitable deposits does not, however, always give the expected result. Recent work on the lead - zinc - baryte - fluorite deposits in the north of England have caused us to re-examine the conditions under which the Pennine mineralisation has occurred, in particular, those in the Askrigg and Alston Blocks. The results show that the apparently very similar deposits are, indeed, rather different. The Askrigg data yields a temperature about 100-150°C, within the range for sedimentary hydrothermal deposits, but the Alston Block data has recently been revised upwards by approximately 100°C as a result of sulphide assemblage studies, and are now back within the classical range for igneous hydrothermal deposits. As they say, there is nothing so constant as change. It is inevitable that in the 1980s a number of deposits will revert to being classified as partially of igneous hydrothermal origin. Whilst we no longer expect the source of the metals to necessarily be igneous, we still need a heat source to circulate the minerals within the sedimentary strata.

The next speaker was Professor Ager from University College, Swansea, who took as his subject 'Changes in the Rate of Change'. He started by quoting comments made by Rudolf Trümpy in his Presidential Address to the last IUGS congress:

> Geologists are beginning to realize that even improbable events become probable during a sufficiently long time span. Catastrophism is probably the wrong word, but episodicity and periodicity loom large in the minds of today's geologists.
>
> We have come a far way from the positivist, ruddy-faced uniformitarianism of 10 years ago.

Ideas that have come into the fore in the last 10 years include S J Gould's concept of punctuated equilibria, which suggests that large periods where species are in equilibrium are periodically interrupted by sudden changes. This fits in very well with the fossil record as we know it, where long periods seem to produce the same fossil record. Obviously, if the stratigraphical record itself is interrupted then the fossil record will be interrupted too.

But what is striking is the frequency with which you can find apparently continuous successions where, without any noticeable change in facies, one species is suddenly replaced by another. Hock Cliff on the Severn provides one example of such a change, but perhaps the most splendid demonstration is to be found at Lake Turkana in Kenya, where P G Williamson found during 1981 no less than 190 different mollusc populations in the Late Cenozoic beds. Here many of the changes could be correlated with changes in lake level, which

resulted in changes to many of the species at the same time.

J Maynard Smith has pointed out that the idea of new species arising within 50 000 years of one another seems sudden to a palaeontologist, but gradual to a geneticist. It is the nature of the record that we cannot find the smaller levels of changes but can only recognise the grosser changes. Despite many man-years of work on the Mesozoic brachiopods around the world only one good example of the process of evolution has been identified. This occurs in the Middle Lias, where the *Homoeorhynchia acuta* has been replaced by the *H meridionalis,* by a process known as allopatric speciation.

If you look at some of the sections to be found in the Western High Atlas mountains of Morocco you find ripped-up black algal mat material in a limestone matrix which appears to be storm deposited. Detailed studies of the rate hurricanes have been hitting the Texas coast over the last century or so suggest that any point on the coast has a 96.5% chance of being hit by a hurricane in a 3000 year period. Study of the Moroccan sections suggest a similar rate for bed deposition, one hurricane/storm deposit per 3000 years. In fact storm deposits are now being recognised throughout the stratigraphic column and all round the world.

The classic littoral Lias deposit of South Glamorgan, the Sutton Stone, can now be interpreted as a storm deposited bed. What used to be considered as a fossilised pebble beach formed over a period of some 3 million years can now be looked at as a storm deposited bed laid down one Thursday afternoon! It is always important to separate observations from deductions. The sediments of the South Glamorgan Lias deposits are the evidence we can rely on. The theory that these beds represent a steady marine transgression is only a deduction, and could easily be replaced with a theory of a storm deposit piling up sediment accumulated over millions of years.

Recent work by Fred Broadhurst and his colleagues in Manchester on the Coal Measures has identified buried trees that remain in an upright position, indicating that they must have been buried in a catastrophic event rather than being slowly covered with sediment. If the latter had been the case the tops of the trees would have rotted away before the tree was completely buried. A similar conclusion can be drawn concerning beds that contain the escape burrows of non-marine bivalves that have had to cut through a sudden flood deposit. It has been suggested that the sandstones were produced by monsoon conditions whereas the silts, which contain no escape shafts, were deposited in the intervening dry seasons.

Another concept that has changed somewhat over the last 10 years is geomorphology. It used to be thought of as resulting from a gentle continuous weathering process, with pebbles breaking off mountain faces and being transported downstream and redeposited. But if you look at some old photographs of mountainous areas it is striking how little weathering has really occurred in the last century, even in areas that suffer from extremes of climates. Pictures taken on the Green River in Utah in 1871 and 1968 show the cliff faces to be almost identical.

A look at the deep gullies that cut into the chalk hills of southern England suggests that they were cut during a short span related to a particular climatic episode in post-glacial times. Similarly a look at the Juras shows mountains with steep cliffs covered by scree where little of the scree is of recent origin - it is all well covered by vegetation, often on a base of fairly thick soil. Probably the scree all formed in Late Pleistocene times, and it has remained in this state ever since.

In Norway there are landslips at Ramnefjell that show no signs of weathering in the 80 years since large areas slid into the fjord, causing great changes to the local scenery. And in Malta one of the collapse structures is known to have been formed in the Middle Ages very suddenly indeed. Events like this suggest that it is the sudden, violent episodic events that have the greatest impact on the geology we find in the field.

Some 22 000 years ago a natural dam at Missoula in Montana burst, releasing the waters of a 700m

deep lake. This water flowed across what are now Idaho and Washington states and stripped the top layers of the Columbia Plateau away to form the Channeled Scablands the area is now known for. Places like Davin Coulee and Grand Coulee were eroded through basalt to depths of up to 300m in a matter of a few weeks, not over a period of millenia.

If you look at the reality behind the concept of seafloor spreading you soon find that this is not a continuous process either. If you look at the episodic nature of the Tertiary deposits in both the Anglo-French Basin and up the eastern seaboard of the USA it is interesting to speculate how they may have coincided with the opening of the North Atlantic during the same period. Possibly the rise and fall of the sea levels can be related to the rising and falling of the Mid-Atlantic Ridge.

Continental collisions are even less likely to be a gradual process than seafloor spreading. Whilst India was travelling across what is now the Indian Ocean during the Jurassic and Cretaceous there was little geological activity, but once it hit Asia in the Miocene we find more evidence of geological change. About 10 years ago Terence Hughes suggested that Cordillean North America originated in Asia and sailed across the Pacific during the Mesozoic. This theory goes a long way towards explaining why Californian geology differs so markedly from that of the rest of America.

Another type of catastrophic geological event is meteor impact. We tend to think of these as something that happens on other planets, but we now have evidence of about 90 impacts on the Earth, including the Reiss Crater in Germany and Lake Siljan in Sweden. Recently suggestions have been made that the Sudbury ore complex in Ontario is also the result of a meteor impact. In the Gabon there is evidence for a large impact type structure in the Precambrian, and ten other impacts in the Phanerozoic have been calculated to have had a greater effect than a 150 000 000 megaton atomic blast.

Digby McLaren has suggested that the devastation of the Devonian shallow marine benthos at the end of the Frasnian may have been due to meteorite impact. It has also become fashionable to blame the extinction of the dinosaurs on a similar cause, with the high iridium levels in thin clays at the Cretaceous-Tertiary boundary in Italy and Denmark being cited as evidence of an impact at that time. If, however, we take into account the fact that the clay was deposited at a much slower rate than the surrounding carbonates, it is possible that the concentration of iridium is evidence of the rate of deposition rather than of the amount of iridium in the atmosphere. The clay is, however, evidence for an episodic nature of deposition, rather than a catastrophic one. In fact Wezel has recently found that a clay band lower in the Cretaceous succession has a higher iridium content than the band at the boundary with the Tertiary. But Alvarez has suggested there was not enough time to accumulate the iridium at this latter boundary, as he has calculated that a 10 million year period would be needed. Another factor is that manganese nodules also show high iridium concentrations, which suggests a higher than usual iridium fallout.

In a recent work of Professor Ager's the term 'event stratigraphy' has been proposed to cover the concept that stratigraphy should be correlated by reference to events rather than fossils, sediment type, isotope content or fission tracks. This concept seems to have been accepted, as evidenced by a recent issue of *Episodes* containing a paper by Meulenkamp emphasising episodicity and contemporaneity of major tectonic events in the Hellenic and Calabro-Sicilian arcs in the Mediterranean.

At the end of the Miocene there is evidence of a major Messinian event during which the Mediterranean dried out, giving extensive evaporite deposits in Sicily, Italy and Libya. It has been suggested that this event caused the down cutting of the front of the Alps, in the area that has since been filled by the Italian lakes. If this did happen it is possible that, when the Straits of Gibraltar were breached, the Mediterranean filled up in a few weeks - yet another possibly catastrophic event that could be used to fuel the controversy.

Professor Ager summed up by pointing out that there had been a marked change over the last 10 years in our perception of the rate at which geological changes take place, and that this would probably be confirmed by research that will be carried out over the next 10 years.

Our final speaker for Sunday morning was Dr. P. Martin of Essex University, who undertook to tell us the geological history of the five terrestrial planets in just one hour, which works out at a mere 375Ma per minute! This is equivalent to asking Leakie to cover the history of man in less than 0.1 seconds. Fortunately the five terrestrial planets had similar early histories, and some have shown very little activity for very long periods.

It is only in the last 15 years that we have been able to undertake detailed planetary exploration, and whilst our knowledge has increased enormously over this time it is still very sketchy. Our Earth-based observations of planets such as Mercury and Venus were very superficial. Mercury is too close to the Sun for good observation, and Venus is covered in cloud. Radar was only just starting to be used at this time, and most of the other wavelengths were not available for observation through the Earth's atmosphere. We knew about the 'canals' on Mars, and had mapped the nearside of the Moon but were only just coming to know the farside. The only terrestrial planet we had any real knowledge of was the Earth.

Many different techniques have been used to enable us to begin to understand the geological history of the Earth, but for the other terrestrial planets the main source of information is the photographic mapping, carried out at a number of wavelengths, of their surfaces. Some space probes have attempted chemical analysis of soil and atmospheric samples, to measure magnetic fields and quakes and to carry out simple tests, but only on the Moon has any extensive testing been possible, and then only because we have sent men there. Until this was done it wasn't even possible to ascertain with certainty whether the craters on the Moon were of impact or volcanic origin, so with the other planets much of our knowledge will probably have to be updated when we can finally make observations in situ.

What are the factors that control the nature of the surface of a planet? There are two competing types of process, external and internal. External factors range from meteorite impacts, through wind storms, rain and running liquids to processes such as frost shattering and landslides. The internal processes include vulcanism and metamorphic deformation, both of which are ultimately derived from the passage of heat from the centre to the surface.

On the Moon the most prominent surface features are the impact craters. They range from very small, caused by the impact of cosmic rays on the surface, to huge areas many hundreds of kilometres across, which are referred to as basins. The larger the crater the flatter its bottom, and for the very largest ones there is often a rise around the impact zone in the centre.

If, as we now think, the terrestrial planets were formed out of the dust and gas surrounding the proto-Sun, the fact that a lot of material impacted with them during their formation is hardly surprising. The newer craters on the Moon, which stand out because of the lighter coloured rays of vitrified glass radiating from them, result from impacts of the few remaining meteoric bodies that are still orbiting the Sun. We do not see the rays on the older craters because the glass becomes devitrified under the impact of cosmic rays. Whilst the younger craters are well formed, and often display slump terraces and linear fractures around the inner walls, the older craters are much more degraded and altered. Some of the larger ones even get filled by lava.

The very largest craters, the basins, are surrounded by a number of concentric rings. Most of the mountains on the Moon consist of segments of a ring around a basin. The size of the basin forming impacts was enough to fracture the surface of the Moon, and lava came flooding out of these fractures to cover the floor of the basin at a later time.

But the Moon isn't the only terrestrial planet that is pock marked by craters. Ten years ago we were able to obtain photographs of one hemisphere of Mercury, and that took three separate passes. These photographs revealed that the surface of

Mercury is very similar to that of the Moon, despite its much greater density - which means that ejected material doesn't travel as far on Mercury, so any secondary craters are much nearer to their source. Given its small size, its high density indicates that the core contains a high proportion of metals and is also proportionally bigger than the Earth's. The mantle surrounding the core is consequently fairly thin. Whether convection occurs within the core, or whether some other mechanism causes Mercury's magnetic field, is still uncertain. We now know that Mercury has a soil similar to that on the Moon, caused by the impact of small meteorites and cosmic rays rather than chemical or biological agents. We know that the surface of the Moon is very old, so we must presume that Mercury's surface is also around 4000M years old.

When only one hemisphere of Mars had been photographed it was thought that Mars was similar to the Moon as far as its surface features were concerned, but later photographs of the northern hemisphere showed that the planetary surface is not homogenous. (Perhaps the same will prove to be true on Mercury.)

Many of the craters on Mars are similar to those on the Moon and Mercury, but there tend to be fewer small craters on Mars. This is probably because Mars had a much denser atmosphere at the time most of the impacts occurred. Some craters seen exhibit flow structures that are thought to be the result of the impact melting a permafrost cover to produce a slurry that soon freezes again. This indicates that the Martian surface has probably also been affected by a type of erosion not seen on the Moon or Mercury - chemical erosion.

The presence of a liquid, presumably water, on the surface of Mars can also be used to explain some other erosion features. It has hastened the erosion of the craters, which are noticeably more degraded than those on the Moon, and has probably caused the sinuous channels we see running across the surface. They could also have been affected by the Martian winds, which can be quite strong. Some channels closely resemble river valleys. It has been suggested, however, that they are the result of ice travelling just below the surface breaking up the soil enough for wind ablation to cause the channels.

If, however, water was the agent we must explain where it has gone, because the polar caps of Mars consist principally of frozen carbon dioxide. Perhaps the water was in the atmosphere that has been lost from the Red Planet. Today water could not stay on the surface of Mars. It is now thought that this loss may have occurred as long as 4000M years ago, about the time of the last of the meteorite impacts.

Mars also has large basins which have been flooded by lavas. These may also contain some of the material that has evidently been eroded away from the vast canyons such as the Vallis Marineris, though at present we are not certain where all this eroded material ended up.

The lavas on Mars are probably different in their origin from those on the Moon. On the Moon the lavas are mainly restricted to the near side, principally because the nearside is lower than the more rugged farside. In total about 17% of the nearside has been flooded by lava, and it is even possible to identify some of the lava tubes through which the lavas passed. The lavas on Mars were very mobile, but as they cut many of the sinuous channels that are thought to be water derived they are not likely to be directly associated with the cratering episodes but, as in the case of the Moon, are geologically younger.

The one feature on Mars that is not seen on Mercury or the Moon are the huge shield volcanoes. The largest is some 24km high, and over 600km in diameter. The lava spreading from these shield volcanoes covers hundreds of kilometres. In fact the whole surface of Mars is distorted by a huge rise called the Chryse Rise, which contains a number of these huge volcanic structures. Associated with some of these volcanoes are huge grabens, indicating crustal extension with faulting and downdropping of strata. These probably formed as the magma chambers which fed the volcanoes extended the crust as they filled. Similar grabens are seen on the Moon, but Mercury has not shown any. In fact Mercury shows evidence of the reverse process, crustal contraction, in the form of a

series of thrust faults. The Moon also has some of these, indicating that it has suffered both crustal shrinkage and expansion.

When the Viking landers finally sent back pictures of the Martian surface to us we were able to see the that the rocks are vesicular and crystalline in nature. We were also able to see permafrost forming, and have seen how it can form trench-like structures as it freezes and thaws.

Venus, like the similarly sized Earth, has an appreciable atmosphere. In fact the atmospheric pressure on the surface of the planet is some 100 times that on Earth, and the temperature is high enough to melt lead. Yet Russian landers have made it to the surface and have shown us that the surface is covered by angular rocks, so the surface must be being renewed by some process. On the other hand radar mapping through the cloud layer has revealed circular structures that are thought to represent the remains of impact craters. As yet we know very little about this hostile environment. We have only just managed to penetrate its clouds of sulphuric acid droplets, and it will be some time before we understand Venus.

What distinguishes Earth from the other terrestrial planets? It is still geologically active, and its atmospheric density has been sufficient to allow the formation of oceans. Whether its volcanic activity is any greater than Mars is uncertain, but it does seem to have more crustal activity than the other planets. Perhaps the next ten years will show us just how different, or similar, it really is to its neighbours. To do this we will need to study more than just the surface features that can be seen in photographs. More money will be needed before we can answer the many outstanding questions.

Our final speaker was Professor Knill of Imperial College, who took as his subject 'Developments in Engineering Geology, 1972-82'. Engineering geology, as a subject, has a British history of some 30 years. From the early 1950s to the 1960s there were only a few people working in the field and, hence, there was relatively little development. The next decade saw the establishment of a journal and a number of groups and organisations connected with the subject. The last decade has seen the international recognition of the field, though it is likely to be another decade before it becomes recognised as a fully fledged discipline.

When discussing engineering geology it is important to distinguish between geological complexity and geotechnical complexity. The spillway for the Micarcreek Dam in British Columbia is a good example of a cutting through a complex geological situation, containing complexly folded gneisses, which is geotechnically straightforward. The spillway was cut as a series of benches which bore no relationship to the rocks they cut into. Equally, a straightforward looking, single bed situation can be a nightmare to the engineering geologist.

In any international field it is important that the participants use an agreed terminology. The 1970s have seen a systematic improvement of the description of rock masses. In general this has led to a trend away from the principally geological terms previously used. In particular, engineering geologists are particularly concerned with the stages of weathering a rock has passed through. A dramatic example of the effects of weathering can be seen on Lan Tau in Hong Kong, where a section through a hill showed that the fresh rock core is surrounded by rock exhibiting varying stages of weathering, down to a point where the granite had been reduced to a soft sand. The contact between the two zones is fairly sharp, though unweathered boulders can be found within the weathered areas. Driving piles into such strata results in a very uneven base for building on. Whilst only one geological province is involved the area is a complex one for the engineering geologist. Yet a similar situation in Oman has a completely different result, because the dry climatic conditions have resulted in the weathered rock being blown away, leaving solid core stones behind. So any internationally recognised terminology must take into account the climatic conditions as well as the rock type.

When building tunnels such as the Megget tunnel from St. Mary's Loch to Manor Valley in the Southern Uplands it is necessary to ensure you

know what rocks will be encountered whilst drilling, and how good they will be at supporting the walls and roof of the tunnel. In this case the strata consisted of heavily jointed greywackes and grits interbedded with vertically bedded siltstones. The various beds were graded according to the internationally agreed terminology and the cost of drilling the tunnel was estimated on the basis of this classification. It can be embarrassing if elaborate calculations of the percentage of each of the classifications expected to be encountered is later found to be inaccurate! In fact the last ten years has seen a rise in those who seem to believe the description of rock is an end in itself. We must, however, never lose sight of the fact that such descriptions are only a tool in establishing timescales and costs for engineering projects.

Another area that has seen great strides in the last decade has been underwater geological engineering. The North Sea and Channel Tunnel projects have provided a stimulus in this area within Britain. Seismic techniques are heavily used, but these cannot provide all the information needed. When a drill rig sits on the sea bed it is necessary to be sure that the bed has sufficient strength to ensure that the impact of waves on the rig do not result in a horizontal shearing of the supporting surface. Once drilling has proved the oil reserve we then need to determine whether the underlying rock is sufficiently strong to support a full oil production platform.

One discovery of interest in the North Sea in the last decade was that the seabed in various areas was pock-marked by shallow depressions. At one stage it was thought that these might represent unstable areas in the underlying rocks, but the current consensus is that they represent gas release structures which are not of crucial importance to the engineering geologist.

The last decade has also seen a lot of work in the arid areas of the world, which present their own unique problems. Such environments often contain salt deposits just under or on the surface, which can also lead to the groundwater being a brine. The main problem is that concrete is susceptible to attack by salts, including gypsum. Other problems in desert areas include the danger of burial under wind blown sand and the effects of the flash floods caused by the very infrequent, but violent, rainstorms.

Another area where there has been a lot of development in the last decade has been the field of hazard assessment. Again Hong Kong provides specific examples. In the 1950s there was a vast influx of refugees from China who were housed in vast collections of multistorey blocks of flats that were hastily put up. Sites for these flats were prepared by slicing the tops off a number of hills and using the surplus material as fill for the valleys and seashore. Being in the typhoon zone Hong Kong is subject to periods of very, very heavy rainfall. In 1972 one such rainy period caused the Po Shan disaster. A hillside under excavation had been undercut, and the water seeping through the soil caused a landslide that knocked over one multistorey block, which in turn struck its neighbour.

In 1976 the same sort of sequence occurred at Sau Mau Ping after some 50cm of rain had fallen in a 24hr period. This resulted in a 2.5m depth of totally saturated topsoil, which flowed down the slope into flats, killing some 17 people in the space of a few seconds. The problem was that the uncompacted fill material was very easily penetrated by the rain. There are now some 40 to 50 engineering geologists working in Hong Kong to ensure that similar disasters do not occur. Where necessary retaining structures have been built to ensure that any slips that do occur are only of a local nature.

A more familiar hazard is that provided by earthquakes. In earthquake areas it is very important to site reservoirs at places that do not show evidence of recent earth movement, a fact that seems to be forgotten in all too many cases. If a reservoir is sited in such an area the very event of the reservoir filling up can change the isostatic pressure sufficiently to cause further earth movements.

But reservoirs can become hazards for completely man-made reasons. One classic example of this was the Teton Dam in Idaho, which was constructed from from loessic material using the local, very silty, soil. This was placed against an open-jointed rhyolitic lava. As the water started to fill

the dam it flowed past the dam on its way from the spillway, leaving cavities within the structure of the dam which quickly caused its failure.

The other area where engineering geology has become increasingly important is in the reduction of the cost of civil engineering projects. This is becoming increasingly important with the current state of world recession, and requires that more, and more accurate, geological surveying be done at the planning stage. An example of what can happen if the surveying does not reveal the likely hazards occurred during the building of the Kariba Dam North Bank Power Station in Zambia. During the excavation of the main machine hall large chunks of gneiss started falling from the roof of the hall. The problem was identified as resulting from horizontal bands of schist within the gneiss that occurred at the noses of folds within the metamorphic material. The contractor was told to treat the excavation as if it were a mine, so delaying the project. Only one borehole had been drilled in the region being excavated, and the contractor claimed for the extra cost of this unexpected delay. A long, drawn out, dispute took place between the contractor and the Zambian government over who should pay the extra costs incurred.

The results of the geological engineer's survey also determine the type of machinery that is used at a site. Again this can play a crucial part in the profitability of a contract. For soft material bulldozers can be used, and well jointed or weak rock can often be pulled out by use of a ripper attachment on a bulldozer. If these methods cannot be used you have to resort to drilling and blasting. Underground various types of tunnelling machine take the place of the bulldozers and rippers.

A further problem that has interested engineering geologists over the last decade has been how to protect tunnels from roof falls. One method is to apply a layer of shotcrete as the tunnel is cut. This is especially useful in softer or more friable rocks.

Another problem comes in finding suitable fill materials for projects such as dams. It is important that quarries developed specifically to provide suitable fill material produce a high percentage of usable fill. As local sites are advantageous for cost reasons, the cost saved by such processes should not be wasted by choosing a site that requires a lot of unusable rock or soil to be removed before suitable material can be obtained. One example that occurred in Britain was the building of the motorway system around Portsmouth from locally quarried chalk. The chalk was transported to the sites, 1km away, by conveyor belts, but by the time it arrived it had been abraded to soft, slurried material.

It is possible to underestimate how useful locally available materials would be. If you asked most people whether you could use the pillow lavas of the Troodos Mountains on Cyprus as fill they would say no. But when you study how these lavas weather you find that they quickly produce a gravelly, sandy material with a very low clay content which is potentially very suitable for construction purposes. In developing countries the use of unconventional local materials that would be frowned on in the northern hemisphere is often essential if a project is going to be economically feasible.

As civil engineering projects get bigger and bigger new problems arise. Nowadays it is often easier to stabilise a potential landslip area rather than to just dig out the unstable rock (or resite the project). This can be particularly important where it is found that a shallow angle would have to be used if the slope was to be stabilised by being cut back. Concrete retaining walls and steel bolts can save a lot of excavation in such situations.

It is the engineering geologist's job to anticipate the problems that will be encountered, and to find the most cost effective way of handling the problem. In the coming decades the need for engineering geologists will become even stronger.

Once again the Conference was summed up by the OU's own John Wright. John pointed out how the people who actually use geological data in their work, such as Professor Knill and Dennis Jackson, rarely concern themselves with those two words so beloved of others studying geology, plate tectonics. They are more concerned with the nature of rock and the presence of any 'ongoing tectonic activity'.

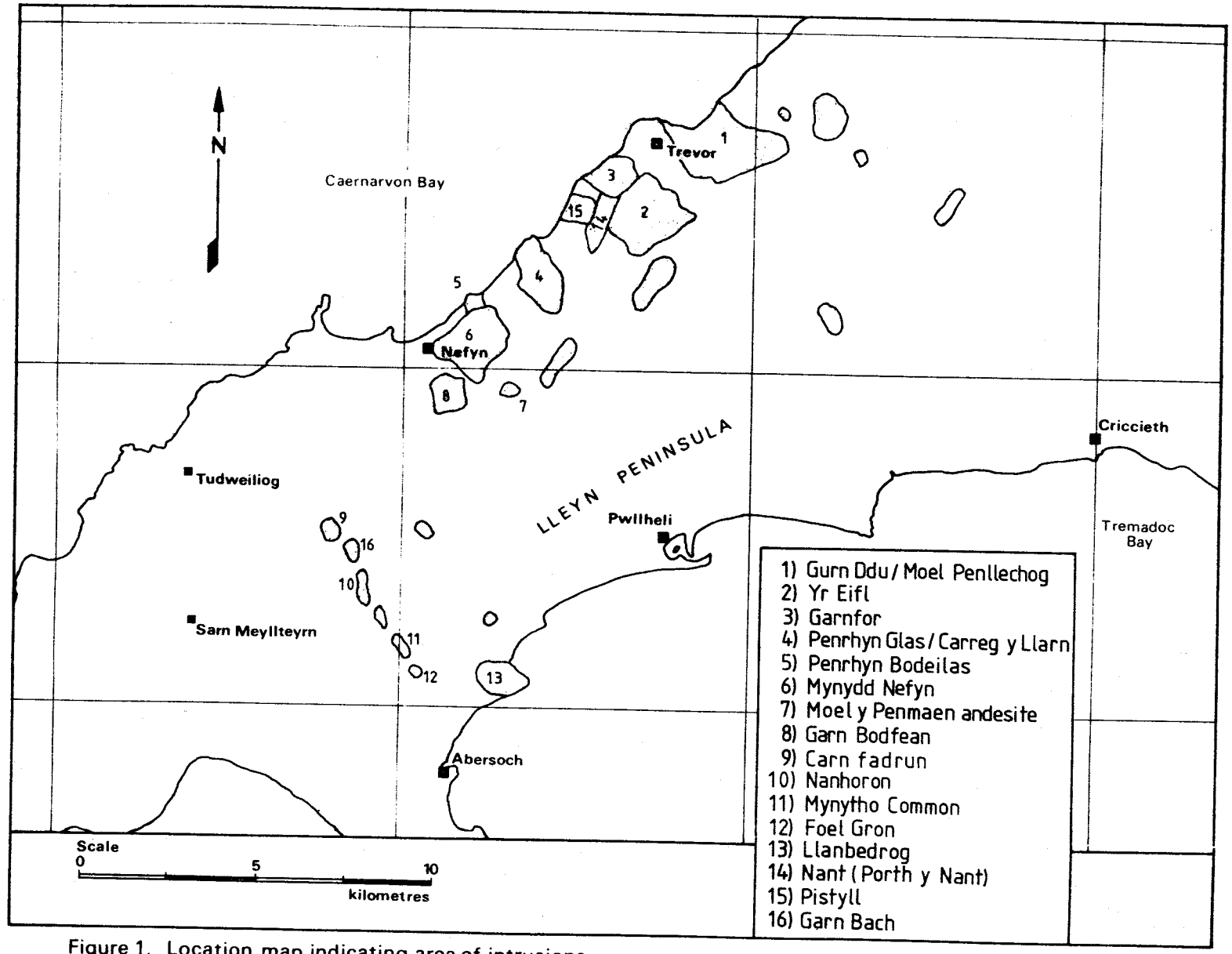

Figure 1. Location map indicating area of intrusions

Some Geochemical Characteristics of Granitic Intrusions in the Lleyn Peninsular

A report on a current OU research project

Gladys Viggars

The Lleyn Peninsular is penetrated by over twenty granitic intrusions exposed within Lower Palaeozoic sedimentary and volcanogenic formations. The intrusions are microtonalites, microgranodiorites, microgranites, granophyres or felsites which form stocks generally of less than 5km^2 in outcrop area (see Figure 1).

Until 1980 the only geochemical studies of the intrusions in this area were by Tremlett (1962, 1964, 1972). Tremlett's early field studies led him to the conclusion that many of the intrusions were emplaced subsequent to the supposedly Caledonian (Silurian-Devonian) faulting of the area. His geochemical studies revealed that there were differences between 'known Ordovician' and 'known Caledonian' intrusions and, on the basis of this evidence, he felt confident that other intrusions in the area could be assigned to the Ordovician or the Caledonian.

In 1980 Croudace undertook a more detailed geochemical study of these intrusions and discussed their petrogenesis. He concluded that all the intrusions were mid-Ordovician because they were related to the Caradocian andesitic lavas of Moel y Penmaen.

The aim of my research project is to review all the current data, obtain new data where required and, hopefully, to draw some conclusions concerning the relationships of these intrusions to each other and the surrounding volcanic rocks.

176 rock samples have so far been collected (including 52 Snowdonian granites). Thin sections of 107 samples have already been made, and 76 samples have been crushed and analysed, using energy dispersive X-Ray Fourier (XRF) analysis, at Nottingham University and the OU. The samples were analysed for major elements and certain trace elements.

Both Tremlett and Croudace grouped the intrusions in small sub-groups, according to their geochemical characteristics. Tremlett recognised an early granodiorite suite at Garnfor, which was followed by the emplacement of felsites, then by a multiple intrusion and, finally, by a microgranitic stock. Their emplacement and distribution was claimed to be controlled by Late Caledonian (Early Devonian) faulting; this faulting establishing the time of emplacement for the intrusions. Tremlett claimed that the geochemical and petrographic variations of the granodioritic suites resulted from progressive contamination of an acid magma by basic rock at depth. He based this view on the apparently increasing abundance of dolerite xenoliths from the microgranodioritic to microtonalitic rocks, and on good correlations on Harker diagrams (plots of element oxides against SiO_2) for samples ranging in composition from dolerites to felsites.

Croudace came to different conclusions about this group. He concluded that the granodiorite was related to the Moel y Penmaen andesitic lavas by fractional crystallisation (which would provide strong evidence against a Silurian/Devonian age). His variation diagrams show strong linear relationships for most elements against SiO_2, with Moel y Penmaen at one end and the felsite at the other.

Variation diagrams combining the data from Tremlett and Croudace with new data obtained

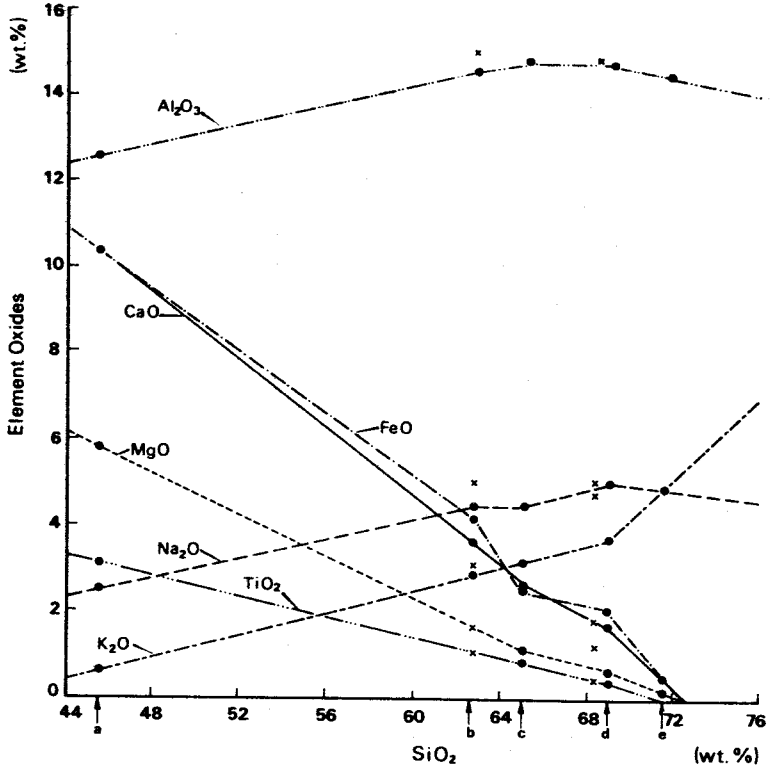

Figure 2. CaO, MgO, Na_2O, K_2O, TiO_2, FeO and Al_2O_3 are plotted against SiO_2 for a Dolerite, Garnfor granodiorite and Yr Eifl microgranite.

- ● Tremlett's data
- × New data
- a Dolerite
- b Inner Garnfor
- c Marginal inner Garnfor
- d Outer Garnfor
- e Yr Eifl

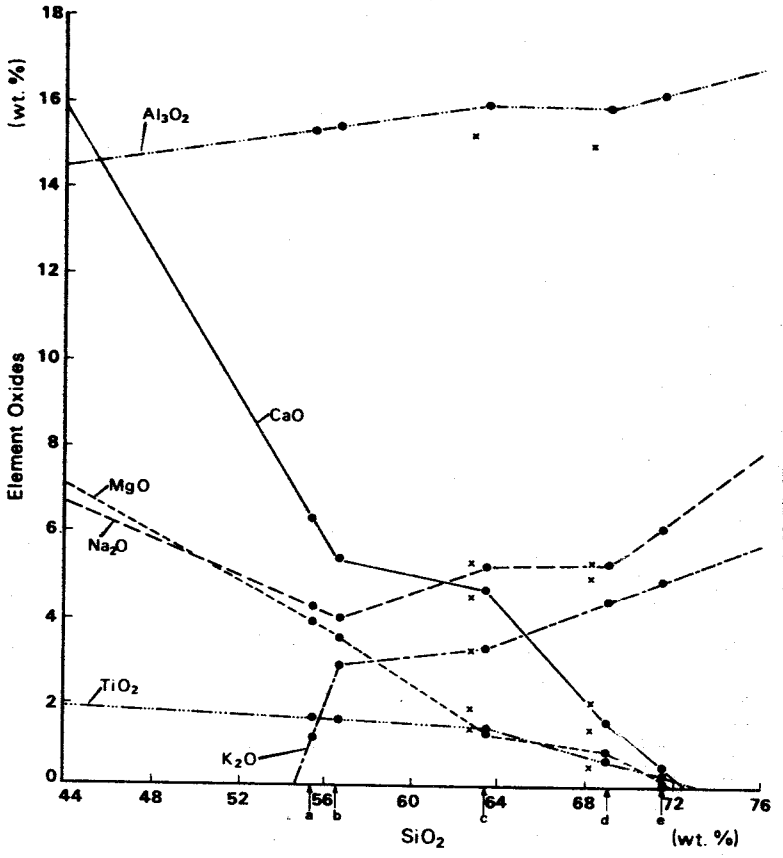

Figure 3. Al_2O_3, CaO, Na_2O, K_2O, MgO, TiO_2 are plotted against SiO_2 for Moel y Penmaen andesite, Garnfor granodiorite and Yr Eifl microgranite.

- ● Croudace's data
- × New data
- a Moel y Penmaen
- b Moel y Penmaer
- c Garnfor (inner)
- d Garnfor (outer)
- e Yr Eifl

from my own research are shown in Figures 2 and 3. On this type of plot simple contamination would yield a straight line. We can conclude from Tremlett's data that simple contamination of an acid magma by basic igneous material, such as the dolerite, was not feasible. To yield a straight line plot the basic rock must consist of 16% FeO, 4.3% MgO and 1% TiO_2 at 44% SiO_2.

Further analysis was obviously required, so ten samples were collected from the Garnfor granodiorites for analysis. Plotted onto Harker diagrams the analyses fell into two distinct groups:

- SiO_2 from 62-63%
- SiO_2 from 67-68%.

The 62-63% is found in the Inner Garnfor rocks, whilst the 67-68% is found in the Outer Garnfor suite, but adding this to the Harker diagrams provides little new information. Further data on the basic rocks of the area is obviously required, and will be collected shortly.

Croudace placed the intrusions of Penrhyn Bodeilias, Mynydd Nefyn, Carreg y Llam, Pistyll, Llanbedrog and Yr Eifl microgranites, and the Moel y Penmaen andesite, into another group. Tremlett also places these intrusions (excepting the Moel y Penmaen andesite and Llanbedrog) in a group, and concluded that the intrusions originated from a common magma hybridised by a partly crystallised basic magma, the assimilation of the solid rock being indicated by xenoliths. He also believed the Penrhyn Bodeilias intrusion to be a later, coarse-grained, phase of the Mynydd Nefyn magma.

A further sub-group consists of Gurn Ddu, Gurn Goch, Moel Penllechog, Bwlch Mawr and the Moel y Penmaen andesite (see Figure 1). Croudace concluded from his studies that these sub-groups all belong to the same family, but that variations in their petrogenesis produced the observed difference. He also concluded that fractional crystallisation was the most probable mechanism, with the removal of augite, hypersthene, plagioclase, magnetite, apatite and zircon from the Moel y Penmaen lavas. More samples from these areas are now being analysed, and further data will then become available to test this hypothesis.

The intrusions of Foel Gron, Nanhoron and Myntho Common (see Figure 1) form a peralkaline group. The general consensus for the evolution of peralkaline rocks involves the extensive fractional crystallisation of anhydrous minerals from transitional or alkaline mafic magmas. Most oversaturated peralkaline rocks are found in regions of the crust undergoing tension or extension, or in stable intracontinental settings. They may also represent a residual melt from a differentiating body of transitional (or mildly alkaline) tholeiitic magma. A Zr/Nb variation diagram has been used to evaluate the origin of these rocks (see Figure 4).

In any liquid/solid system the relative abundance in the liquid of a pair of elements such as Nb and Zr will be constant if the bulk distribution coefficients between the crystalline and liquid phases for the two elements are very low (<0.1). If the abundance of any pair of such elements in the liquids thus derived are plotted against each other the locus will be a straight line. Such a line will project through the origin, with the slope determined by the concentrations of the two elements in the initial liquid. Those elements which are almost completely retained in the liquid phase during any solid/liquid reaction, or at equilibrium, have been termed incompatible elements.

In the various suites plotted in Figure 4, Nb and Zr have behaved as incompatible elements. This indicates that the Moel y Penmaen andesite and the granitic intrusions which lie on the line in Figure 4 are geochemically related. The intrusions lying on the line are Moel y Penmaen, Bwlch Mawr, Penrhyn Glas, Moel Penllechog, Foel Gron and Nanhoron. This almost certainly implies a genetic relationship since the values of the incompatible element ratios for each intrusion were determined by the composition of the initial liquid or solid, from which they are derived.

Garnfor and Llanbedrog do not lie on the line and are probably not, therefore, related to the Moel y Penmaen andesite. The Llanbedrog granophyre, however, may have derived from Moel y Penmaen by fractional crystallisation of phases with lower Zr/Nb variation (eg magnetite), and Yr Eifl

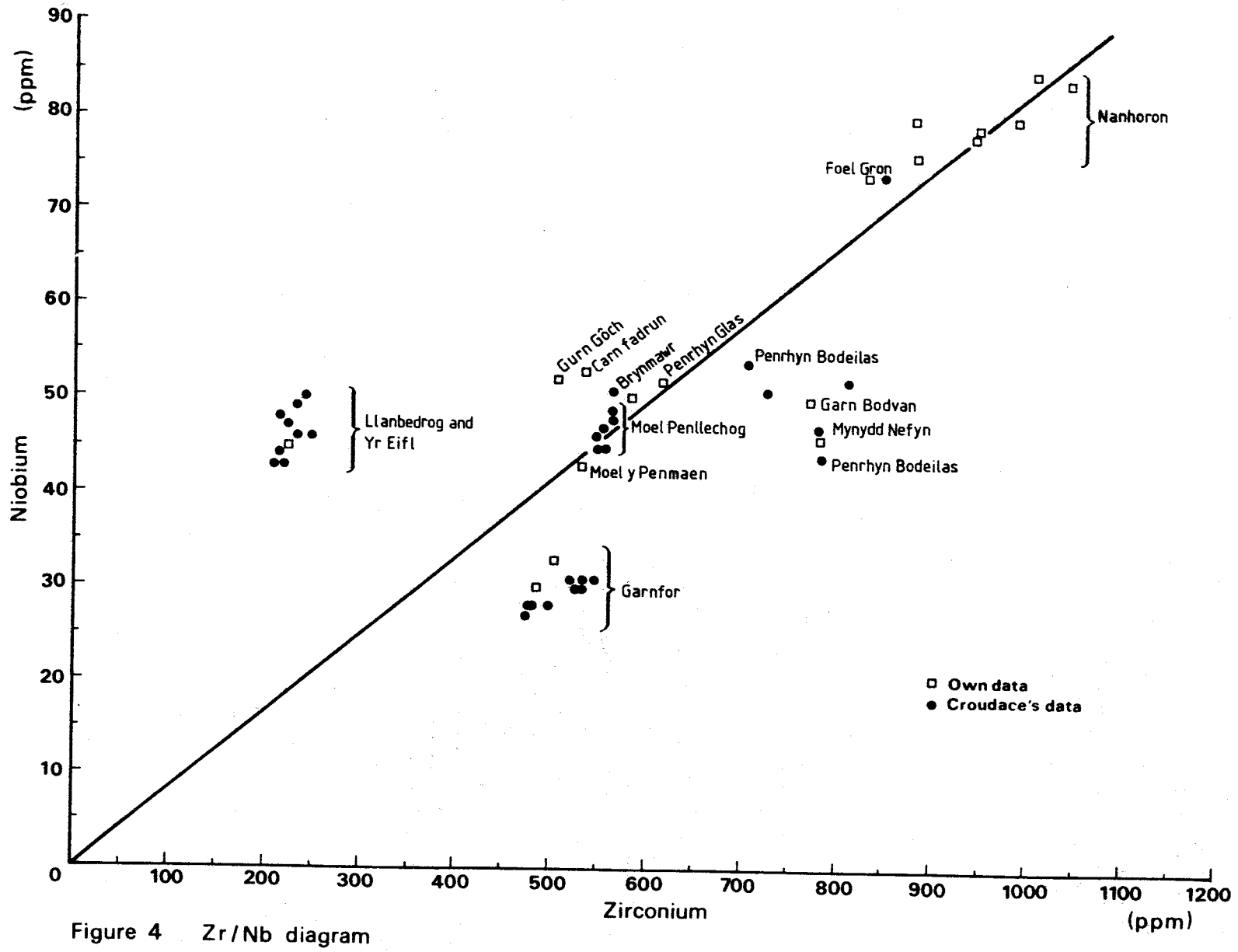

Figure 4 Zr/Nb diagram

by fractional crystallisation of phases with higher Zr/Nb (eg zircon), from a magma with Zr/Nb equivalent to the Moel y Penmaen andesite. This contradicts Croudace's hypothesis, and also Tremlett's. As my work progresses, and more analyses become available, I shall be able to put forward my own ideas regarding the petrogenesis of these intrusions.

Part-time research is far more difficult than full-time research (someone else could solve the problem before you!) but it is very rewarding and is the logical follow-up to an OU degree.

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A Visit to Spitzbergen

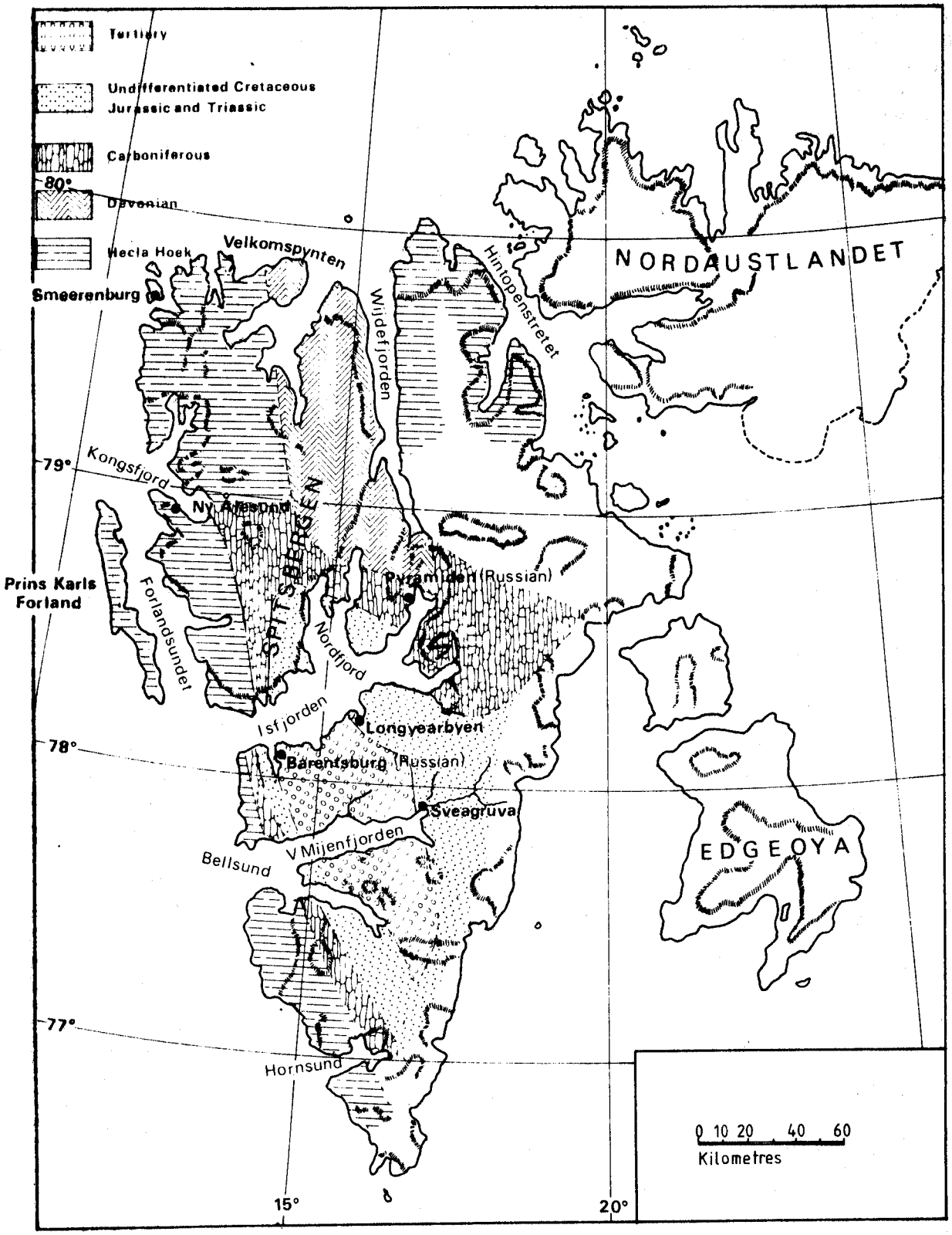
Arthur Whitehouse

This was not primarily a geological visit but, when we landed in bright sunshine two hours after midnight, geology and its effects were apparent everywhere. After a long flight up the Norwegian coast we had continued across the sea for a distance similar to that from England to Spain. As we landed at the capital, Longyearbyen, the horizontally bedded strata of the dissected plateau were immediately obvious.

This plateau is over 1000m high and is deeply cut by glaciated valleys. It consists of a North-South elongated trough of Tertiary rocks surrounded by Mesozoic and Upper Palaeozoic rocks. Beyond these, on the west coast, are the Caledonian mountains, which are highly folded and metamorphosed. It is the latter's pointed peaks that gave rise to the name Spitzbergen. The rocks are known as the Hecla Hoek, and range from Precambrian to Ordovician in age, which makes them roughly comparable to the Moinian and Dalradian of Scotland (but formed on the opposite side of the Iapetus Ocean, because Spitzbergen was, then, close to NE Greenland).

Our plan was to sail up the NW coast of Spitzbergen, landing at various places to see something of the works of ice and man, and of the rich ground flora and birdlife. We scrambled down to the boat on the shore over muddy ground with a carpet of saxifrages and arctic poppies. Beneath this thin layer of wet soil were perhaps 300m of permafrost. Soon after going aboard the converted fishing boat (MV Copious of Southampton) we were catching up on sleep, in spite of the magnificent scene of mountains, glaciers and sea outside.

Our first landing was on the north side of the 100km long inlet of Isfjord. Whereas in Norway the mountains often fall sheer into the sea, in Spitzbergen the coast is usually surrounded by a strandflat. This lowland plain is a raised beach formed as the great weight of ice melted, and it can be 10km or more wide. As we walked over the strandflat we came upon human skeletons lying on the ground or in very shallow graves (the permafrost only thaws about a metre, or less, during the short summer). The ground was mostly moraine and was treacherously soft.


Tertiary
Undifferentiated Cretaceous
Jurassic and Triassic
Carboniferous
Devonian
Hecla Hoek
80°
79°
78°
77°
15°
20°
Velkomspynten
Smeerenburg
Wijdefjorden
Hinlopenstretet
NORDAUSTLANDET
Kongsfjord
Ny Ålesund
SPITSBERGEN
Prins Karls Forland
Forlandsundet
Nordfjord
Pyramiden (Russian)
Isfjorden
Longyearbyen
Barentsburg (Russian)
Sveagruva
V Mijenfjorden
Bellsund
EDGEOYA
Hornsund
0 10 20 40 60
Kilometres

We passed a camp of Swiss climbers who presumably wanted a change from their own mountains! Many groups come to Spitzbergen in the summer to study or enjoy the countryside, and there are little wooden huts scattered at intervals all round the coast. We met geologists from Cambridge, Bergen and Leningrad, as well as botanists and ornithologists.

There are, however, only five permanently inhabited townships; four of these are coal mining centres, two Norwegian and two Russian, and the fifth, Ny Ålesund, is an old Norwegian mining centre now mainly concerned with the Norwegian Polar Institute's Research Station situated there at 79°N. There are also some archaeological sites, such as the early 17th century whaling station of Smeerenburg now being excavated by the University of Groningen.

It came as a great surprise to learn that only one of the four working coalfields was of Carboniferous age, the other three being Tertiary. I would have expected that Spitzbergen was already too far north by even the early Tertiary for coal to be formed, but apparently the temperatures, judging by the *Equisetum* flora, were not unlike those of southern Europe today. Certainly the coal is of good quality and the main seam is 3m thick.

We left Isfjord to go north up the strait between Prince Karl's Foreland and the mainland but we came to ice floes, at first just a few, then more and more until, finally, the strait was blocked. At the same time we ran into fog. This was in early July and fog is not an uncommon feature of the climate at this time, so we had to retreat and go all the way around the west of the 80km long island. When we landed on its northern tip, to put an ornithologist ashore, we walked over the soft tundra up to a terrace in clear air and brilliant sunshine. Little auks were nesting in myriads amongst the scree of Hecla Hoek boulders coming down from the mountains above.

The next day we explored a now uninhabited place called London, enshrouded in cold fog from the sea. Only a short distance up the mountain there was hot sunshine, where one could comfortably strip to the waist though ice-carved peaks were all around us. We crossed Kongsfjord in the fog, passing close to jagged icebergs (growlers) calved from the glacier, to Ny Ålesund. Here the attractions included the ugly derelict mine buildings; the well equipped research station where, as everywhere in Spitzbergen, removal of boots was the rule as one entered; the northernmost post office and shop in the world and, all round, nesting terns, divers, barnacle geese, eiders, long-tailed ducks, phalaropes, turnstones and snow buntings. All the birds were very tame and all are rigorously protected.

As we made our way northwards we ran along a rocky coast with many huge glaciers coming right down to the sea. Landing was difficult because of a snow and ice encrusted shore, but we landed in a little bay amidst frost shattered boulders. Here we found abundant lichens and mosses, but no flowering plants, and everywhere the arctic birds such as skuas, guillemots, puffins, pink-feet, kittiwakes and glaucous gulls.

We also landed at the place from which Andrée, in 1897, attempted unsuccessfully to fly by airship over the North Pole. The iron filings he used to generate hydrogen were still lying around.

We rounded the NW corner of Spitzbergen and continued NE to 80°N, where we became surrounded by ice and could go no further north or east. We returned and landed at Velkomstpynten. The only welcoming thing was the familiar Old Red Sandstone dipping northwestwards, looking just like that of Britain with fine tension cracks filled with quartz. Otherwise it was cold, bleak and desolate, with the ground frozen almost to the surface and much snow cover. My tendency to wander away from the group was inhibited on these landings by the possibility of meeting a polar bear, with which one had a love-hate relationship. I kept fairly near the man with the rifle! We saw small Svalbard reindeer and wondered at their survival in this sparse landscape. We only found the bones of arctic fox, walrus and whale, but we did see ringed seals and about ten species of bird. Always there were huge logs scattered along the shore which had come down the Siberian rivers and drifted westwards on the arctic currents.

In deteriorating weather, with rain and snow, we made our way south to Bellsund, well south of our starting point. It was interesting to see how nutrients contributed to life in this harsh climate. A green patch on the mountainside would show from afar where there was a seabird colony on the ledges above, and this lush vegetation would in turn provide a habitat for other fauna. Again the melt waters from a glacier snout are rich in minerals, and where they mix with warmer sea water plankton flourish, and hence fish and their prey. Near one glacier snout in Bellsund we counted more than 100 ringed seals on the ice floes, and seabirds were noticeably more abundant in such areas.

Where we landed there was often a wooden hut built from the ubiquitous driftwood - an empty research base where we would sign the visitors book, a crazy hut distorted by an ice pingo beneath the floor, a lone trapper's hut where we would be welcomed with coffee and stories of winter life, a Norwegian geologist's hut where we learnt of their study of the Triassic and its dolerite dykes.

The folding of the Hecla Hoek was superbly displayed in the cliffs of Bellsund. At one point I walked over a huge moraine with a diverse assortment of boulders of the rocks of that formation. Ice brings together such an assortment better than water ever does.

Spitzbergen is a fascinating island of great beauty, with mountains rising to over 1700m. The whole group of islands is now called Svalbard, with Spitzbergen as the largest of them. There are 170 species of flowers, 3 land mammals and about 50 species of bird, some of them abundant. The geology is marvellously displayed once the snow has melted. The political set up, whereby the islands are administered by Norway but with equal access to other treaty signatories, could be a model for other places. There are now extensive national parks and nature reserves and these are certainly contributing to the conservation of both natural and historical features.

Adam Sedgwick, Geologist and Dalesman 1785-1873

It is difficult to read about Adam Sedgwick, absorb his words, look at his achievements or notice the effect he had on his friends and contemporaries without becoming very aware that this was a truly great man who had that simplicity of soul, combined with a great love for humanity, that made him one of those exceptionally lovable personalities that impress themselves on all who come into contact with them. He was also, fortunately, a field geologist of the first rank.

He never wrote a book of any length that would enable us to assess him easily in comparison with other nineteenth century geologists, such as Buckland, de la Beche, Lyell, Murchison, Darwin, Ramsay, Geike, etc, who were more prolific in their writings. Nevertheless, his achievements were very remarkable.

He was born in the small Yorkshire town of Dent and he maintained his contact with his origins for all his life. In essence he remained always the simple, honest dalesman. At Cambridge, where he took holy orders, he was elected Woodwardian Professor of Geology at a time when he knew next to nothing about the subject. (This sort of irrational way of making important appointments could happen at that time.) But he set himself the task of changing himself into a geologist and became one of the very best. His lectures, which extended from 1819 to 1870, were remarkably good and well attended, both by students and townspeople. The papers he wrote on such varied subjects as 'The Magnesian Limestone', 'The Structure of the Cumbrian Mountains', 'The Geology of the Lake District' and 'The Internal Structural Features of Rock Bodies, such as Slatey

Cleavage, Stratification and Jointing' demonstrate his great ability as a field geologist.

He investigated and named the Cambrian and, jointly with Murchison, the Devonian systems. His quarrel with Murchison over the latter taking more and more of Sedgwick's Cambrian rocks into his own Silurian system is well known. The fault seems to have been entirely Murchison's, but the eventual estrangement was deeply felt by both men.

The other chief controversy in Sedgwick's career, and one in which he ended up on the losing side, was the stance he took against his former pupil Darwin's *On the Origin of Species*. But his viewpoint was sincerely felt and honestly argued.

Less well known, perhaps, is the key role he played, with the help and support of the Chancellor of Cambridge University Prince Albert, in a Royal Commission of 1851-52, which was instrumental in reforming and modernising the old, and in many ways fossilized, Universities of Oxford, Cambridge and Dublin. He thus played a major role in redirecting the way higher education was organised in Britain.

Much in his ideas and outlook anticipated by more than a hundred years the thoughts and ideals that led to the founding of the Open University. Consider the following passage from an 1842 Manchester Guardian report of one of his lectures to the British Association:
"In talking to the men whose brows were smeared with dirt, and whose hands were black with soot, I fell upon marks of intellectual minds, and proofs of high character, and I conversed with men who, in their own way, and in many ways bearing on the purpose of life, were far my superiors. I would wish the members of the British Association to mingle themselves with these artisans, ... for as I talked to them the feeling prevailing in my mind was that of the intellectual capacity manifest in the humbler orders of the population of Manchester. ..."

All this is set out in this remarkable book, which I cannot too highly recommend*. The standard work on this outstanding man, *The Life and Letters of the Reverend Adam Sedgwick* by J W Clark and T M Hughes, was published in 1890. A twentieth century look at his life and work, and a reappraisal of him from the viewpoint of our own times, has, therefore, been long overdue. Colin Speakman's biography in twelve themes fills the need admirably. It is not a large book; one wishes there were more of it; but I found it both readable and moving.

Richard Wilding

* Speakman, C *Adam Sedgwick, Geologist and Dalesman, 1785-1873. A biography in twelve themes*, jointly published by Broad Oak Press, The Geological Society of London and Trinity College, Cambridge. Paperback, £4.50.

Bits and Pieces

Yet another filler by myself! Begging bowl in hand (as usual) I left this year's AGM almost emptyhanded again - but with plenty of promises that may turn into something for you next year.

Once again this Journal has been given a professional appearance thanks to Anne Bennett's unstinting efforts in producing the superb illustrations. Perhaps only the authors and myself will ever realise just how Anne manages to improve on our sketches in such a remarkable way. Thank you yet again Anne.

This issue has also seen help from other sources, beside the obvious one of the authors. Especial thanks go to Norma for finally getting the transcripts prepared for me, and to Rosemary Bubb for finishing off her hard work for the Conference by rushing out the last transcript at a time when other pressures were quite intense. I hope you will all appreciate the effort needed to report Conference as fully as we manage to.

Martin Bryan

Branch Report

Brittany 82

Do you ever have a glimpse in your mind's eye of the great God of geology, sitting down there amongst his subduction zones and turbidity currents, gleefully inventing new and complex names and processes with which to confuse us poor mortals?

The six who set sail for St Malo in May with Dennis Bates were in no doubt that He is doing just that. Within an hour of landing we were straight into those enigmatic rocks called migmatites. There is much debate about the origin of migmatites, and much about the age of the St Malo/St Brieuc suite. Are they formed from the very old Pentevrian basement, which goes back around 2000 million years, or are they formed from the Brioverian sediments which were deposited on top of the Pentevrian between 750 and 1100Ma ago? Their migmatisation appears to have taken place during the Cadomian orogenic cycle, which was an early phase of the Caledonian, and resulted from the subduction processes which occurred then.

Migmatites form at the extreme of metamorphic conditions, when melting is beginning to take place. They form at depths of some 20km when the temperature reaches about 650°C, and are found not far from granites which release water from micas and amphiboles to aid the melting process.

On the peninsula of St Jacut de la Mer we were able to see various stages of the migmatisation process. In the early stages we could see the brecciated agmatites formed when the quartz and potassium feldspars, being the first to melt, had separated into bands of leucosome (light coloured material) surrounding the darker, unmelted, melanosome. In the second stage the leucosomes began to exhibit ptygmatic folding - highly contorted mini-folds.

Where only partial melting has taken place the rocks are referred to as metatexites. Progressively higher grade melting involves the mafic minerals, biotite, amphibole and garnet, and the structures become successively schlieren (streaked) and nebulitic. As the distinction between leucosome and melanosome becomes less and less apparent the rock is referred to as a diatexite.

Enough of migmatites. Let us away to Quimper, with its beautiful cathedral, for our assault on the Crozon peninsula, with its fossiliferous sediments from Cambrian, Ordovician, Silurian and Devonian times. Crozon is the little, central, peninsula of the Brittany headland, just south of Brest. The beds dip steeply so that a walk along the beach is a progression through geological time.

At Camaret we scrambled over the Ordovician sandstones of the Grés Armoricain to find fossil beaches with ripple markings and trace fossils, such as footprints, left by trilobites long ago. Overlying the sands of the Grés Armoricain are Llandeilien shales of the Upper Ordovician, and here a trilobite called *colpocoryphe rouaulti* was found, and a solitary graptolite.

A nearby headland exposed an interesting feature in an eroded anticline in the sandstones. The centre of the anticline had been eroded away to leave the roots forming the two arms of a bay perhaps 1km across, together with several small islands which, no doubt, gave the headland its name of Tas de Pois

A walk over hills covered in brilliant yellow gorse brought us to Veryac'h. Here Silurian shales dipped at an angle of some 60° and yielded graptolites. Monograptoids abounded in such quantity that the problem was to find pieces with few enough of them to distinguish one from another. A little higher in the succession we found curved *cyrtograptus* fossils.

A few hundred yards further along the beach brought us to Devonian limestones, again highly fossiliferous. Many bivalves surrounded the coral *favosites*, and one block held a lovely straight nautiloid. Regretfully we had to leave the fossils, feeling as always that there are more exciting creatures to be found, and vowing to return some day to find them.

We now turned ourselves northwards to the igneous rocks again. The Ploumanac'h granites are magnificent. The whole coast glows pink - no wonder it is known as the Côte du Granite Rosé.

At Pors Roland a series of granite dykes, at first sight apparently parallel, drive out from the cliffs and across the beach to disappear under the sea. These are a set of radiating dykes emanating from the granite mass just inland. The granite mass contained some large xenoliths - black, basic, rounded inclusions surrounded by the pink acid granite. Large pink feldspar crystals abounded in the granite, and some of the phenocrysts were embedded in the black xenoliths. Those who know the Shap red granite quarry will have seen similar examples. (*Isn't that all OU geology students? Ed*)

In some blocks the pink orthoclase phenocrysts were surrounded by a shell of oligoclase, giving the granite a rapakivi type of texture. Elsewhere the black biotites had been concentrated into bands in the granite, making overlapping curves which indicate successive currents of movements in the pasty magma. Typical granite tor structures stood out above the surrounding landscape and across a shallow bay, spheroidal weathering having made good use of the block jointing in the granites.

We finally arrived in St Brieuc and, having settled in the Youth Hostel, were ready for our look at more of the metamorphics of this area. Our first call was to the town rubbish tip - Les Ordures - a remarkably interesting place!! The sands shone and glistened as the sun caught the mica flakes from which it was compounded. An amazing number of biological trace fossils in the course of formation were found.

Birds left footprints and beak tracks where they had fed and many burrowing worms left their marks in the sand.

It was here that we were to see the effects of pressure metamorphism, shearing and thrusting. First stop was to examine mylonites - rock ground to powder in a shearing zone and then reformed so that no discernible particles could be seen. From this extreme we progressed through steadily reducing pressure zones within Briovenan conglomerates. Pebbles normally are rounded - here they were squeezed into long, flattened oval shapes, and aligned to indicate the pressure direction, which operated at right angles to the long axis of the pebbles. Some pebbles were even bent over in a U-shape. Others had been compressed in such a way that a pressure shadow was left at the ends of the long axes. These gaps were then infilled by quartz crystals enclosed within the orientation lines of the surrounding groundmass. Samples of these could be collected from the loose boulders on the beach.

At Tournemine and Binic we were able to examine Brioverian turbidite deposits, which are very much like turbidite sediments of any other age. Our last two days were, unfortunately, surrounded by the Breton fog, so the panoramic views of the coastal scenery were hidden.

Our final day was spent in the Erquy area, first on La Pointe de la Heussaye, looking at the spillite lavas and tuffs. Here were some of the largest pillow lavas ever manufactured. One single pillow was eroded at beach level to make a cave at least 10m across and 7m high, which we could walk into for some distance.

The final stop was on the Erquy sandstones and quartzites. Attractively coloured, with banding in pink and buff, these rocks are arkose sands of Late Cambrian age, interspersed with beds of conglomerates. They appear to be of dry desert origin and have been metamorphosed to varying degrees - some hardly at all so that individual grains of sand can still be seen. Cross-bedding was found in several places.

Our thanks are due to Denis Bates for so clearly expounding the geology to us, and for guiding and driving the party. Also to Kay, who carried out the administrative arrangements.

Besides the geology we were left with many memories. Binic harbour in the mist, music relayed over the square in almost every village, the minah bird singing the Marseillaise in a shop in St Brieuc, gigantic ice creams and Breton crêpes, the Fête-noz near Quimper, a merry evening at an English-style pub near Benodet, Kay posing on top of one of the standing stones at Camaret, and Denis playing Irish tunes on the recorder in the mist at Erquy.

When do we go again?

Alan Dawn

Grand Canyon and Bust

Ah! the memories of the OUGS-organised American Experience. Geology-wise the exposures, like everything in America, were huge. 200km long, 100m high cliffs at 1500+m! 1500+m deep holes with 1500+m climbs out of them!! The unforgettable fog along almost 1000km of murky grey Pacific coast!!!

The places were even weirder. Cities with 50 homes, houses 40km or more apart, and we even managed to cross a Zzxyz Street after leaving the Canyon de Chelly (pronounced Shay!) and before getting to Boron, Onyx and Quartzsite.

Even the meals were huge. The size of their crabs claws sent shivers down my spine, and the steaks speak of huge monsters somewhere in the deserts of Texas.

On top of all this we were forever being warned to beware of the bears, rattlesnakes, scorpions, black widow spiders, skunks and chipmunks. Fortunately we failed to see the spiders and scorpions, and saw the bears and rattlesnakes from a safe distance - but wait until you hear the tales about the skunks and chipmunks - they'll make your eyes water!

We arrived in Phoenix to find that the 94°F at 7pm was considered to be the end of a cool day. Having decided that this was to be a 'laid back' trip we all jumped into the pool conveniently situated immediately outside our motel rooms. An evening swim in the desert is certainly better than one in the North Sea!

By lunchtime next day we had succeeded in extricating our 7m long, 4m high Recreational Vehicles (RVs to Americans, mobile luxury homes to us Brits) from the hire company and had set off along our first 200km of freeway - on the right side even! It wasn't until we decided to make our first geological diversion up Oak Creek Canyon that we discovered that all American roads aren't straight and wide - in fact the road out of Oak Creek was a maze of hairpins, with 'narrow bridges' that would only just take two RVs abreast. The canyon takes you from the Devonian Martin Formation of the Verde Valley through the spectacular Carboniferous Redwall Limestone and Supai Beds, which form the buttes and vivid red canyon walls of the lower canyon, and then leads you up onto the Recent lava platform that forms the Mogollon Rim above the Permian Kaibab Limestone. It provides a very good introduction to the beds that form the Colorado Plateau.

Monday morning saw an early start for all three vans so that we could make our 9.15am rendevous at the Museum of Northern Arizona in Flagstaff. After an initial introduction to the local geological features, through the medium of the excellent geological exhibits in the museum, by one of the museum's guides we were taken across the road to the museum's laboratories for a look at their current research projects. Paul Clasby's day (and possibly trip) was made at this point by our being introduced to Edwin Colbert, one of the world's leading 'dinosaur hunters', who

spent a couple of hours showing us how they were extricating dinosaurs from 20 tonne blocks of rock inside the main lab and explaining the significance of his recent work in Antartica. Before we left he showed us the huge fossilised tree trunks from the Petrified Forest area that were lying around the museum's backyard. David Elliot, an ex-patriate English assistant professor in the University of Arizona's Geology Department, also joined us to advise on what we should look for at some of the sites we intended to visit.

Leaving just before midday we made our way towards Sunset Crater (via, for our van at least, the Lowell Observatory). Sunset Crater's cone was formed to the east of Mt. Humphrey (the highest of the San Francisco Peaks at 3850m) in 1066 - an easy date for us to remember. The cone still has a classical shape, and the surrounding lava flows are still mostly bare of vegetation. A trail takes you around one of the flows, even giving you a chance to explore one of the ice-covered (despite temperatures of around 80°F outside!) lava tubes. After a short lunch break we headed for another 'local' attraction - Meteor Crater - a mere 80km away. Despite commercialisation this 1250m wide, 170m deep impact crater situated on a large, windy, flat plateau is very impressive. Another 100km drive took us past our first sight of the Little Colorado River to our second night's campsite at Holbrook.

From Holbrook we proceeded to the southern entrance to the Petrified Forest National Park to see the huge silicified logs (of a family related to the sequoias) that make up the Crystal Forest. Other attractions in this park include the lunar landscape of Blue Mesa, the indian heiroglyphics on the cross-bedded sandstones of Newspaper Rock, the colourful Teepees (an appropriately shaped rock formation rather than the real things) and a view out over the Painted Desert. We then travelled on to Canyon de Chelly, stopping on the way at the famous Hubbell Trading Post on the Navajo Indian Reservation.

The Canyon de Chelly is a bifurcated canyon system some 350m deep and 100km long. It is justly famed for the beautiful orange-red cliffs on which the local indians have, over the course of millenia, built cliff dwellings and even complete pueblo villages. Chosen principally for the ease with which it could be defended, the canyon through the Permian De Chelly Sandstone provides in its irrigated valley bottom some of the most fertile land in this otherwise mostly barren desert plateau.

Next day saw us heading across the desert towards the Grand Canyon in a snow storm. (You couldn't say this trip wasn't varied!) It was quite interesting listening to the local Navajo/English radio station saying the snow would not settle below 7000ft whilst watching the snowploughs clear the road for us at 6000ft! I feel that by listening to enough dual language adverts we could eventually have learnt to talk to the Navajo, but the indians generally still don't look too friendly. (Maybe the two 5m high arrows at Two Arrows coloured our judgment slightly though!)

We made two stops on the way to the Canyon, the first to visit Dinosaur Steps near Tuba City and the second at the spectacular 500m deep gorge formed by the lower part of the Little Colorado River just before it joins the Colorado at the northern end of the Grand Canyon. Shortly after stopping at the gorge overlook we entered the Kaibab National Forest that covers the southern rim of the Grand Canyon. Our first view of The Canyon, said by some to be the largest hole in the world after Chicago, was from the Desert View Overlook at the eastern end of the main canyon. From there we drove the 50km to the Grand Canyon Village, the starting point for the two trails down into the canyon.

Thanks to supreme efforts by Paul we had managed to convince the Park Rangers that they did have enough passes to allow us to travel down into the Inner Gorge and the Colorado River, a mile below the South Rim campsite (as the crow flies!), so the next morning seven of us set off down the steeper of the two trails, the South Kaibab Trail. Apart from the fact that this trail is better for going down than coming up, because it has no water along its 11km length, it offers the geologist another major advantage - every other contact zone is clearly identified by informative noticeboards placed alongside the trail. In this way we were introduced gradually to the eight beds between the Permian Kaibab Limestone forming the canyon's rim and the Precambrian Vishnu Group that is exposed by the Inner Gorge. This latter group of schists and pink granites creates an aura of quiet serenity at the bottom of this impressive canyon.

Our overnight stay at the Bright Angel Campsite was enlivened, according to those of the party who failed to sleep through it, by an attack by what eventually became an army of chipmunks and skunks. Personally I still can't see how you can feed an army on one sandwich and a few of the leftovers that were to form the party's scanty breakfast - but then I slept through the fun! It was on the way back up that we felt the debilitating effects of this raid!

We came back up the 15km long Bright Angel Trail, going down the river until we could follow Pipe Creek and Garden Creek along the Bright Angel Fault to the springs at Indian Gardens. At this stage we were almost half of the distance back, and still felt fairly fresh. Unfortunately we had chosen to ignore the fact that Indian Gardens is only 500m above the Colorado River, whereas the South Rim is 1000m above Indian Gardens! We shouldered our packs and started up, stopping wherever possible to examine 'interesting formations' - ie anything that looked as if it allowed you to sit in the shade for a while. I knew I had climbed the massive Redwall Limestone from the ache in my legs rather than the evidence of my eyes. Collapsing at the top I waited gratefully for the (small) remainder of the party to catch us up. Catching the free bus back to the campsite gave us one last pleasant memory of our feat - our bus driver was a guy we had met in the Inner Gorge the day before on his way *up* the South Kaibab Trail, having come down it the same day!

The next day was spent recovering from our endeavours whilst we travelled on to Page and the Wahweap Marina on the shores of Lake Powell. On the way we stopped off at Marble Canyon to see the Colorado River flowing under Navajo Bridge, the replacement for the Lees Ferry crossing 10km upstream. Our party were

fortunate enough to arrive in time to see two of the 12-man rafts that offer rides down the Grand Canyon pass down the river to their first set of rapids.

Lake Powell is a 300km long flooded valley system formed by the Glen Canyon Dam at Page. 80km up this lake a side canyon leads to Rainbow Bridge, the largest natural arch in America (and, therefore, the world!). The narrow, twisting, flooded canyon takes you to within 200m of the 90m wide, 100m high sandstone arch. 115hp speedboats allow you to make the trip from the nearest town (Page) in a day, but you have to keep up a fair speed to do it. An even faster way to do it is to take a Lear jet like the one that flew over us at 25m or so on the way back - but they can't land at the Rainbow Bridge Marina!

Our port of call for Monday was Bryce Canyon in Utah. Arriving at the park's Visitor Centre at what we thought was lunchtime we had a rude awakening - it was already mid-afternoon! We had unwittingly entered a different time zone as we crossed the state line. Bryce Canyon is a misnomer. The area covered by Bryce Canyon National Park is, in fact the eastern edge of the Paunsaugunt Plateau, one of a series of stepped plateaus that break the Tertiary Wasatch Formation. The Paria River is slowly eating away the eastern edge of the plateau, but a massive dolomitic cap protects the softer underlying carbonates, resulting in the formation of stacks called hoodoos. Describing these adequately in mere words is impossible - try to see some of the photos if you possibly can, because they can show the true beauty of this the queen of national parks.

One thing I can warn you of though - Sunset Point and Sunrise Point are misnamed. Sunset Point has to be visited well before the sun sinks, and the sun doesn't get to the Silent City hoodoos until at least an hour after sunrise - as we found out with a patient wait after a very early start in the dark. Following an early breakfast some two hours after we woke we headed for Zion Canyon, the site of some of the most impressive cross-bedding in the USA. Passing through the mile-long tunnel at the top of the canyon we descended a series of hairpins to the Virgin River, the cause of this 1000m deep canyon whose surrounding peaks were named as temples to gods by their Mormon discoverers. Visiting the Narrows where the river emerges into the main canyon we saw the damage caused by the spring floods that had made the trail into the backcountry impassable.

The next day we followed the Virgin River to St. George and then Lake Mead and the Hoover Dam, before spending a night on The Strip in Las Vegas. From here we crossed the very hot, bleak, Mojave Desert into California (only just having enough petrol to get over the Sierra Nevada to Onyx!). After a night at Lake Isabella we went on to see the splendid Sequoia National Park Giant Forest and, nearby, the largest, and one of the oldest, living things, the General Grant Tree. Time did not allow us to see Kings Canyon, unfortunately, so we headed on for Yosemite, only to find that, like Blackpool Beach, it is a place to avoid on a summer weekend. Having failed to park in the main camping area we squeezed into a car park near one of the falls, but quickly decided that the crowds weren't for us. Rather than spend two days here we headed instead for San Francisco and, thereby, saw Fishermen's Wharf on a Sunday - its busiest day! The spare day allowed us to spend a morning sunbathing (in increasingly foggy weather) and the afternoon exploring the delights of Nob Hill and Chinatown. Unfortunately the fog on the coast made trips on the Bay or to the San Andreas impractical.

Fog dogged us next day on our way down the coast past the Monterey ophiolite complex and San Simeon to Ventura. The next day was just as bad, so instead of sunbathing on the beach we had a quick look at Hollywood and a rather disappointing Disneyland before making our way back across the Coastal Range. In fact our campsite at Banning was no clearer, but a few miles drive the next morning brought us back to the sunshine in Palm Springs. Giving up dreams of the sunny Pacific we headed for the beaches on the edge of the Salton Sea, a mere 75m *below* sea level. Temperatures around 100°F made it ideal for sunbathing, but an algal bloom had reduced the oxygen level in the lake so much that the fish were being asphyxiated, and 'drowned' fish along the foreshore did not make the area very congenial, so we soon headed up into the Joshua Tree National Monument. The Joshua trees are only found in the east of the park, but our campsite on the west was half a mile from an oasis (a very small water seepage from a rock that was surrounded by palms) and near an old silver mine in the local quartz monzonite. The silence was only punctuated by the calls of the many species of birds that visit the oasis in the stillness that only comes with the beautiful dawns and dusks of the desert.

Phoenix was still cool (95°F) on our return, so we plunged once more into the pool to cool off after repacking at the end of our three week tour of the southwestern states of the USA. All we had to look forward to now was Conference, Summer School and Christmas - so after a year of constant planning perhaps the next year will be a bit of a disappointment!

Martin Bryan

Walton Hall's First Field Trip to Cornwall

The first weekend in May saw an influx of OUGS members into Cornwall, where they were greeted by gales and cold weather. Those who were lucky enough to arrive at lunchtime on Friday were able to visit the Luxulyan quarry that afternoon. This quarry is in the St Austell Granite, which is highly altered and is consequently quarried for china clay. The St Austell Granite contains feldspars several inches long which exhibit very apparent zonation. We found samples of Luxulyanite, a tourmalinised granite in which large crystals of pink feldspar lie in a dark bluish matrix of tourmaline, often with well-formed crystals.

On Saturday morning we visited the De Lank Quarry, which is in the Bodmin Moor Granite. We were able to see large slabs of granite being cut out and sliced. Polished samples of the granite, and the ubiquitous Shap Granite, were seen. The

Shap Granite is transported from Cumbria to De Lank for cutting and polishing. Some superb Shap xenoliths were observed.

After sheltering from the rain we moved on to Delabole Quarry. This is a slate quarry in the metamorphic aureole of the Bodmin Moor Granite. The country rocks are Upper Devonian in age and were originally fine-grained shales and silts. We visited the small museum and were privileged to be allowed into the quarry itself (it is not normally open to visitors).

After a quick lunch we rushed to the northwest, hoping for a paddle and a sunbathe. We found a strong, cold, wind so had to observe the geology instead! Crackington Haven and Millhook Haven both show highly contorted Carboniferous strata. The beds of shales and sandstones show recumbent zig-zag folds and many faults.

We then returned to our guest house and cottages, aptly named 'Washaway Your Troubles', for an excellent meal of chicken and chips.

Sunday morning was quite leisurely. We first visited the Wheal Martyn China Clay Museum, which was of great interest - especially the local numeral (*I'm only following the copy, honestly! Ed*) collection. We then departed for Roche Rock, a small outcrop of quartz-tourmaline schorl, which is hydrothermally altered granite. This is a no-hammering location, but a few specimens were found lying in the grass.

After lunch we again went to the beach, but on the south coast this time. Again we were met by a howling gale, but this did not stop one of our party from jumping in the sea for a swim - fully clothed too! At Carylon Bay we looked at the beach deposits of coarse-grained quartz and observed the Lower Devonian cliffs. We then travelled to Polkerris, on the opposite side of the bay, where we found the sand to be mainly composed of mica derived from another set of Lower Devonian rocks.

Monday morning was our last trip. We set off for Cheesewring Quarry, stopping on the way at a road cutting near Doubledois. This is in the metamorphic aureole of the Bodmin Moor Granite again, and contains very contorted metamporphosed sediments. Cheesewring Quarry is in the Bodmin Moor Granite itself, and has a granite tor perched precariously at its edge. A sudden heavy shower made everyone retreat to the pub for lunch, so ending our first weekend trip to Cornwall.

Gladys Viggars

Oxford Branch

As of 30th June we have 24 members and have had two meetings and a field trip during 1982. The first meeting was held in High Wycombe for the benefit of those members living in the south of the area. A talk was given by Lindsey O'Callaghan on 'The Andean Volcanoes' and the fifteen members attending considered it rivalled 'The Flight of the Condor' on BBC.

The second meeting was held at Horton-cum-Studley, where Richard Thorpe gave a talk on 'The Precambrian History of England and Wales'. Fourteen members attended and those doing geology courses this year found the talk most helpful.

A field trip to the quarries around Oxford was led by Dr. Andy Johnson, a new member of the Geology Department at Oxford. Only four members were there due to a variety of calamities, but those on the trip found it very interesting and the weather was ideal.

It is hoped to hold a 2-day field trip in the autumn. The venue and leader are to be decided, but it is possible that we will go to the Mendips again.

Catherine Shephard

West of Scotland

This year we have increased our membership to 23, with 5 family members. We have had quite a busy year. On February 20th Dr Graham Durant took a group of about 10 of us around the Hunterian Museum at Glasgow University, where we were among the privileged few to see the famous Bearsden Fossil Shark before it was made public.

On March 27th about 8 members went on a trip to the Doon Valley. I am told that it was enjoyed by those who went. May 1st-2nd was the much looked forward to weekend in the Solway. We hired a minibus and picked up seven members plus Dr George Farrow from Bearsden. After a false start at 7.15, when the minibus was involved in a slight accident(!) we arrived at our destination and were joined by two more members who just came for the day. The weather started off reasonably well but Sunday, as you may remember, was a disastrous day with gale-driven rain, hail, etc. However, as true geologists we had a wonderful time and would, almost, do it again.

For May 23rd we had a visit planned to Ballantae, but at the last moment our leader had to back out because of a family crisis, and we could not replace him. However, everyone agreed to come anyway, and with help from Bill Marshall-Roberts and Bernice Camlin we had a turn out of 13 for a very informative day.

On June 19th Dr Anderton took about a dozen of us on a strenuous walk/climb up the Campsies. We had wonderful weather - not too hot, thank goodness, as the Dungoyne is no easy climb. We all enjoyed it and the usual pint was more than welcome at the Kirkhouse Inn!

Our next trip, on June 26th, was supposed to be to St Monance in Fife, but due to heavy TMA and weekend school requirements, and the bad weather, it was postponed for a future date.

Sue Briginshaw

Yorkshire in Crummackdale (and vice versa!)

The party assembled at Freizor Land Quarry (793660) at the head of the Buck Haw Brough, a prominent limestone escarpment marking the South Craven Fault. Several aspects of the geology of the limestone were demonstrated, in particular the presence of the alga Girvanella Bed, which marks the end of the Lower Carboniferous sea covering the area. The differences in landform on either side of the fault were also noted.

In driving around the outlier to Austwick the general geomorphology of the area was examined before the party reassembled at the entrance to Crummackdale (733697) for a discussion of further points raised.

The party moved up to Norber (798698) examining the basement rocks and the overlying limestone, conglomerate and breccia. The episodic passage of the conglomerate into the overlying pure limestone was seen, and the Norber Erratics were visited. Certain inferences were drawn from the local succession, and the landscape was re-examined in terms of structure and erosion.

In moving to White Stone Lane (772707) changes in sediment and structure were noted, including the unusual 'positive geology' in which the land profile imitates the sedimentary structure.

Taking the field path towards Moughton Hole, the ridges in the valley floor were pointed out, and at a low hill the exposures were examined. At the summit the scenery was again sampled, noting the presence of the Porcellanous Bed within the limestone (roughly the division between the S2 and D1 subzones) and also the altitude of the unconformity.

At Moughton Hole the banded mudstone was examined, and also the sequence and attitude of the pelagic muds in the hillside. Attention was finally turned to the spectacular scenery and fine karst surface at the head of the valley (787720).

The day's findings were reviewed in terms of lithology and structure. A brief discussion was held in terms of the life of the Caledonian Ocean, the origin of its sediments, amd the effects of the closure of the ocean. The limestone, Yoredale Beds and Millstone Grit were briefly mentioned. Finally the effects of the underlying granite were discussed in terms of the Craven Fault System.

A T M Brittain

(Compare and contrast with the report of the same trip in the last issue! Ed.)

Thoughts on Durham Summer School 1982

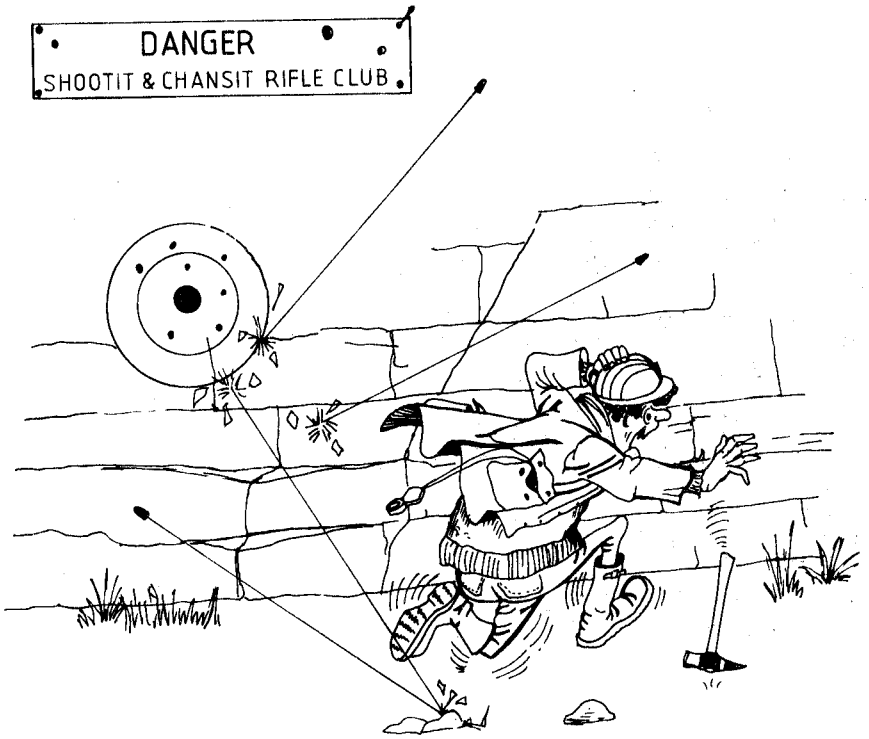
If you think of what we're doing,
  Doing here in all our madness
Rushing wildly round North England
  Finding out what makes North England
Just to please our inner urges
  And, of course, our wonderous tutors
Have you asked yourself the question
  "What on Earth could have possessed us
To inflict upon our bodies,
  On our weak, long suffering, bodies,
To inflict upon our pockets
  Such an overwhelming burden?"
Surely such a foolish action
  Indicates complete and total
Lack of any brain whatever,
  Lack of commonsense or prudence.
Yet we come again for further
  Torture of the mind and body.
Surely such supreme devotion
  Shows we are a dedicated
And select, entusiastic
  Group of very special people.

David Cornubeusis
(David of Cornwall)

Geology
  Is more fun than Biology
Biology is about cutting up frogs and fleas
  Geology is about veins and intrusions and
    refolded folds and such things as Zechstein
    Seas

After Edmund Clerihew Bentley

David Cornubeusis



GE-ODES 2

Quarries and rock faces are used for many things. Make sure of your safety, otherwise that interesting exposure may lead to an exposure of another kind.